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Docket No.: 210424US8

COMMISSIONER FOR PATENTS
ALEXANDRIA, VIRGINIA 22313

RE: Application Serial No.: 09/931,257
Applicants: Naoki TSUKIJI, et al.
Filing Date: August 17, 2001
For: SEMICONDUCTOR LASER DEVICE AND DRIVE CONTROL METHOD FOR A SEMICONDUCTOR LASER DEVICE
Group Art Unit: 2828
Examiner: AL NAZER, L.
Date Allowed: July 1, 2004

SIR:

Attached hereto for filing are the following papers:

Petition under 37 C.F.R. § 1.181
***Copy* of Filing Receipt date-stamped 11/13/03**
***Copy* of Information Disclosure Statement**
***Copy* of PTO-1449**
***Copy* of European Search Report**
***Copy* of Cited References (7)**

Our check in the amount of **$0.00** is attached covering any required fees. In the event any variance exists between the amount enclosed and the Patent Office charges for filing the above-noted documents, including any fees required under 37 C.F.R 1.136 for any necessary Extension of Time to make the filing of the attached documents timely.

Respectfully submitted,

OBLON, SPIVAK, McCLELLAND,
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IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF:	:
Naoki TSUKIJI, et al.	: EXAMINER: AL NAZER, L.
SERIAL NO: 09/931,257	: DATE ALLOWED: July 1, 2004
FILED: August 17, 2001	: GROUP ART UNIT: 2828
FOR: SEMICONDUCTOR LASER DEVICE AND DRIVE CONTROL METHOD FOR A SEMICONDUCTOR LASER DEVICE	:

PETITION UNDER 37 C.F.R. § 1.181

COMMISSIONER FOR PATENTS
ALEXANDRIA, VA 22313-1450

SIR:

37 C.F.R. § 1.181(a)(3) allows petition to invoke the supervisory authority of the Commissioner in appropriate circumstances.

The Applicant respectfully petitions in accordance with 37 C.F.R. § 1.181(a)(3) to compel consideration by the Examiner of the reference cited in the Information Disclosure Statement (IDS) filed on November 13, 2003, re-signed copies of which are attached as well as a date-stamped filing receipt.

The Applicants notes that the Notice of Allowance dated July 1, 2004, did not include an indication that the IDS was entered and considered. Accordingly, the Applicants request a copy of the IDS filed on November 13, 2003, that is signed, initialed, and dated by the Examiner as being considered as required under MPEP 609 III. C. 2., in order to clarify that the references cited in the IDS have been considered and made of record.

Application Serial No.: 09/931,257
Naoki TSUKIJI, et al.

It is respectfully requested that this Petition under 37 C.F.R. § 1.181 be granted and the Examiner compelled to provide the Applicants with a signed and dated copy of the IDS filed on November 13, 2003.

Respectfully Submitted,

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OSMM&N File No. 210424US8

Serial No. 09/931,257

In the matter of the Application of: Naoki TSUKIJI, et al.

For: SEMICONDUCTOR LASER DEVICE AND DRIVE CONTROL METHO FOR A SEMICONDUCTOR LASER DEVICE

Dept.: E/M

By: BDL/CDW/brf

Due Date: November 13, 2003

The following has been received in the U.S. Patent Office on the date stamped hereon

- Information Disclosure Statement
- PTO-1449
- European Search Report
- Cited References (7)
- Credit Card Form for: $180.00
- Dep. Acct. Order Form

Docket No. 210424US8

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

IN RE APPLICATION OF: Naoki TSUKIJI, et al.

SERIAL NO: 09/931,257 GAU: 2828

FILED: August 17, 2001 EXAMINER: ZAHN, J.

FOR: SEMICONDUCTOR LASER DEVICE AND DRIVE CONTROL METHOD FOR A SEMICONDUCTOR LASER DEVICE

INFORMATION DISCLOSURE STATEMENT UNDER 37 CFR 1.97

COMMISSIONER FOR PATENTS
ALEXANDRIA, VIRGINIA 22313

SIR:

Applicant(s) wish to disclose the following information.

REFERENCES

- ■ The Applicants wish to make of record the references cited in the European Search Report and listed on the attached form PTO-1449. Copies of the listed references are attached, where required, as are either statements of relevancy or any readily available English translations of pertinent portions of any non-English language references.
- ■ A credit card payment form is attached in the amount required under 37 CFR §1.17(p).

RELATED CASES

- ☐ Attached is a list of applicant's pending application(s) or issued patent(s) which may be related to the present application. A copy of the patent(s), together with a copy of the claims and drawings of the pending application(s) is attached along with PTO 1449.
- ☐ A check or credit card payment form is attached in the amount required under 37 CFR §1.17(p).

CERTIFICATION

- ■ Each item of information contained in this information disclosure statement was first cited in a communication from a foreign patent office in a counterpart foreign application not more than three months prior to the filing of this statement.
- ☐ No item of information contained in this information disclosure statement was cited in a communication from a foreign patent office in a counterpart foreign application or, to the knowledge of the undersigned, having made reasonable inquiry, was known to any individual designated in 37 CFR §1.56(c) more than three months prior to the filing of this statement.

DEPOSIT ACCOUNT

- ■ Please charge any additional fees for the papers being filed herewith and for which no check or credit card payment is enclosed herewith, or credit any overpayment to deposit account number 15-0030. A duplicate copy of this sheet is enclosed.

Respectfully submitted,

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COPY

SHEET 1 OF 1

Form PTO-1449 (Modified) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTY DOCKET NO. 210424US8	SERIAL NO. 09/931,257
LIST OF REFERENCES CITED BY APPLICANT	APPLICANT Naoki TSUKIJI, et al.	
	FILING DATE August 17, 2001	GROUP 2828

U.S. PATENT DOCUMENTS

EXAMINER INITIAL		DOCUMENT NUMBER	DATE	NAME	CLASS	SUB CLASS	FILING DATE IF APPROPRIATE
	AA	5,754,574	5/19/98	Lofthouse-Zeis et al.			
	AB	5,684,590	11/4/97	Sanders et al.			
	AC						
	AD						
	AE						
	AF						
	AG						
	AH						
	AI						
	AJ						
	AK						
	AL						
	AM						
	AN						

FOREIGN PATENT DOCUMENTS

		DOCUMENT NUMBER	DATE	COUNTRY	TRANSLATION YES	TRANSLATION NO
	AO	0 813 272	12/17/97	Europe (in English)		
	AP	0 618 653	10/5/94	Europe (in English)		
	AQ	0 920 095	6/2/99	Europe (in English)		
	AR	37 06 635	9/15/88	Germany		X
	AS	198 28 427	2/10/00	Germany		X
	AT					
	AU					
	AV					

OTHER REFERENCES (Including Author, Title, Date, Pertinent Pages, etc.)

	AW	
	AX	
	AY	
	AZ	☐ Additional References sheet(s) attached

Examiner	Date Considered

*Examiner: Initial if reference is considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

COPY

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Europäisches Patentamt | European Patent Office | Office européen des brevets

Zweigstelle in Den Haag Recherchen-abteilung | Branch at The Hague Search division | Département à La Haye Division de la recherche

Schwabe - Sandmair - Marx
Stuntzstrasse 16
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ALLEMAGNE

Datum/Date
17.10.03

Zeichen/Ref./Réf.	Anmeldung Nr./Application No./Demande n°./Patent Nr./Patent No./Brevet n°.
53 574 VIII	01125409.1-2214-

Anmelder/Applicant/Demandeur/Patentinhaber/Proprietor/Titulaire
THE FURUKAWA ELECTRIC CO., LTD.

COMMUNICATION

The European Patent Office herewith transmits as an enclosure the European search report for the above-mentioned European patent application.

If applicable, copies of the documents cited in the European search report are attached.

[X] Additional set(s) of copies of the documents cited in the European search report is (are) enclosed as well.

The following specifications given by the applicant have been approved by the Search Division:

[X] abstract [X] title

[ ] The abstract was modified by the Search Division and the definitive text is attached to this communication.

The following figure will be published together with the abstract: 1

EUROPÄISCHES PATENTAMT · DEN HAAG · EUROPEAN PATENT OFFICE · THE HAGUE · OFFICE EUROPÉEN DES BREVETS · LA HAYE

REFUND OF THE SEARCH FEE

If applicable under Article 10 Rules relating to fees, a separate communication from the Receiving Section on the refund of the search fee will be sent later.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 12 5409

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	DE 37 06 635 A (SPINDLER & HOYER KG) 15 September 1988 (1988-09-15) * column 5, line 63 - column 6, line 30; figures 3,6-8 * * column 7, line 27-52 * * column 8, line 17 - column 9, line 37 * ---	1-36	H01S5/024 H01S5/068
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A	DE 198 28 427 A (LITEF GMBH) 10 February 2000 (2000-02-10) * the whole document * ---	1-36	
A	US 5 754 574 A (JOHNSON JOHN K ET AL) 19 May 1998 (1998-05-19) * the whole document * --- -/--	1-36	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	9 October 2003	Laenen, R

1

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 12 5409

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 5 684 590 A (SANDERS GLEN A ET AL) 4 November 1997 (1997-11-04) * the whole document * -----	1-36	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
MUNICH	9 October 2003	Laenen, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 01 12 5409

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

09-10-2003

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			JP	2000502841	T	07-03-2000
			WO	9724786	A1	10-07-1997

COPY FILED______ 1

(19) BUNDESREPUBLIK DEUTSCHLAND

DEUTSCHES PATENTAMT

(12) **Offenlegungsschrift**

(11) **DE 3706635 A1**

(51) Int. Cl. 4:
H 01 S 3/133
H 01 S 3/045
// G01B 11/02

(21) Aktenzeichen: P 37 06 635.8
(22) Anmeldetag: 2. 3. 87
(43) Offenlegungstag: 15. 9. 88

DE 3706635 A1

(71) Anmelder:
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(74) Vertreter:
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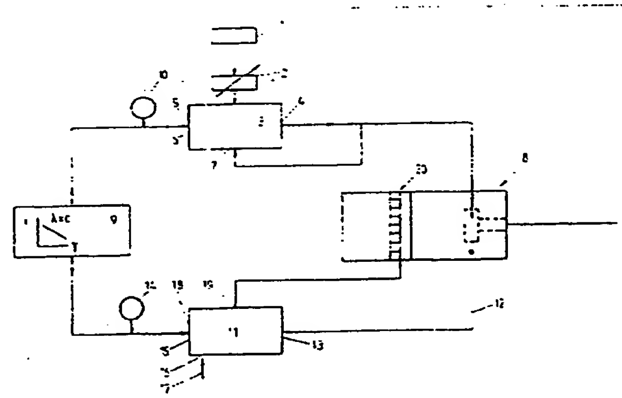
(72) Erfinder:
Abou-Zeid, Ahmed, Dipl.-Phys. Dr., 3155 Edemissen, DE

Prüfungsantrag gem. § 44 PatG ist gestellt

(54) **Verfahren zur Stabilisierung der Frequenz einer Laserdiode unabhängig vom Diodenstrom**

Verfahren zur Stabilisierung der Frequenz einer Laserdiode, in dem die Temperatur des Gehäuses (12) der Laserdiode (8) gemessen und zu Wärmezu- oder -abfuhr konstant gehalten wird. Beim Einschalten des zum Betreiben der Laserdiode (8) erforderlichen Stromes wird die Stromstärke langsam von einem Anfangswert auf einen Sollwert gesteigert. Die Ist-Temperatur (12) des Gehäuses der Laserdiode (8) wird in Abhängigkeit der der Laserdiode (8) zugeführten Stromstärke derart verändert, daß die Laserdiode (8) bei beliebiger Stromstärke Licht konstanter Wellenlänge emittiert. Die Temperaturregelung der Laserdiode (8) entsprechend der Stromstärke wird mittels eines Stabilitätsfaktors $\alpha = d\lambda/(di)/d\lambda/(dT)$ durchgeführt. Das Verfahren wird auch nach Erreichen der Betriebsbedingungen der Laserdiode (8) bei Spannungs- oder Temperaturschwankungen angewandt.



DE 3706635 A1

Patentansprüche

1. Verfahren zur Stabilisierung der Frequenz einer Laserdiode, in dem die Temperatur des Gehäuses der Laserdiode gemessen und durch Wärmezu- oder -abfuhr konstant gehalten wird und anschließend der zum Betreiben der Laserdiode erforderliche Strom eingeschaltet wird, **dadurch gekennzeichnet**, daß die Stromstärke langsam von einem Anfangswert — insbesondere Null — auf einen Sollwert entsprechend der gewünschten Ausgangsleistung der Laserdiode (8) gesteigert wird und dabei, sowie ggf. bei weiteren Veränderungen der Stromstärke, die Temperatur des Gehäuses (12) der Laserdiode (8) so verändert wird, daß die Temperatur der laseraktiven Zone der Laserdiode (8) entsprechend einem Stabilitätsfaktor

$$\alpha = \frac{d\lambda}{di} \bigg/ \frac{d\lambda}{dT}$$

gehalten wird, mit

α[°K/A]	Stabilitätsfaktor
λ[m]	Wellenlänge des Lichts der Laserdiode
i[A]	Stromstärke
T[°K]	Temperatur des Gehäuses der Laserdiode

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die Temperatur der laseraktiven Zone der Laserdiode auch dann konstant gehalten wird, wenn die Stromstärke auf einen Anfangswert — insbesondere Null — erniedrigt wird.

3. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß zum Zwecke der Kalibrierung die Abhängigkeit der Wellenlänge von der Stromstärke einerseits und der Temperatur andererseits gemessen wird, die Steigungen der Kurven der Wellenlänge über der Stromstärke bei konstanter Temperatur und der Wellenlänge über der Temperatur bei konstanter Stromstärke aus diesen Messungen ermittelt werden und durch Quotientenbildung dieser Steigungen der Stabilitätsfaktor α errechnet wird, nach welchem die Temperatur der laseraktiven Zone der Laserdiode (8) konstant gehalten wird.

4. Verfahren nach den Ansprüchen 1 bis 3, dadurch gekennzeichnet, daß als Temperatur des Gehäuses der Laserdiode (8) zu Beginn des Einschaltens des Stromes diejenige Temperatur benutzt wird, bei der auch der Stabilitätsfaktor ermittelt wurde.

5. Vorrichtung zur Stabilisierung der Frequenz einer Laserdiode nach dem Verfahren gemäß Anspruch 1, die eine Spannungsquelle und einen Sollwertgeber aufweist, wobei der an dem Sollwertgeber eingestellte Wert der Stromstärke einem Stromregler zugeführt wird und der Stromregler einen Ist/Soll-Vergleich der Stromstärke durchführt und bei Abweichungen den Wert der Stromstärke korrigiert, der am Ausgang des Stromreglers anliegende Wert der Stromstärke der Laserdiode zugeführt wird und weiterhin ein Temperaturregler vorgesehen ist, der einen Vergleich zwischen der Ist-Temperatur des Gehäuses der Laserdiode und einer vorgegebenen Soll-Temperatur durchführt und durch entsprechende Wärmezu- oder -abfuhr

das Gehäuse der Laserdiode auf konstante Temperatur hält, **dadurch gekennzeichnet**, daß ein Kopplungsglied (9) vorgesehen ist, daß dem Kopplungsglied (9) die Ist-Größen des Stromreglers (3) und des Temperaturreglers (11) zugeführt werden, daß das Kopplungsglied (9) entsprechend dem Stabilitätsfaktor α Führungsgrößen (10, 14) an den Stromregler (3) und dem Temperaturregler (11) derart anlegt, daß die Frequenz des Lichts der Laserdiode (8) konstant bleibt.

6. Vorrichtung zur Stabilisierung der Frequenz einer Laserdiode nach Anspruch 5, dadurch gekennzeichnet, daß das Kopplungsglied (9) Einrichtungen zur Veränderung des Stabilitätsfaktors aufweist.

7. Vorrichtung nach Anspruch 5 oder 6, dadurch gekennzeichnet, daß das Kopplungsglied (9) hauptsächlich aus sogenannten analogen Elementen besteht.

8. Vorrichtung nach Anspruch 5 oder 6, dadurch gekennzeichnet, daß als Kopplungsglied (9) ein Mikroprozessor (21) vorgesehen ist.

9. Vorrichtung nach Ansprüchen 5 und 8, dadurch gekennzeichnet, daß der Mikroprozessor (21) Einrichtungen zur Regelung der Stromstärke und der Temperatur der Laserdiode (8) aufweist.

Beschreibung

Die Erfindung bezieht sich auf ein Verfahren zur Stabilisierung der Frequenz einer Laserdiode, in dem die Temperatur des Gehäuses der Laserdiode gemessen und durch Wärmezu- oder -abfuhr konstant gehalten wird und anschließend der zum Betreiben der Laserdiode erforderliche Strom eingeschaltet wird. Laserdioden eignen sich insbesondere für Längenmessungen mit hoher Genauigkeit. Die gesuchte Länge ergibt sich in Abhängigkeit von Hell/Dunkelstreifen, die durch Interferenz des Laserlichtes auftreten, und der Wellenlänge bzw. Frequenz der Laserdiode. Die Frequenz der Laserdiode muß also zu jedem Zeitpunkt der Messung bekannt sein. Eine permanente Messung der Frequenz der Laserdiode würde einen großen apparativen Aufbau erfordern und, hervorgerufen durch die Fehler bei der Frequenzmessung, die Genauigkeit der Längenmessung verringern. Es erweist sich daher als unumgänglich eine Laserdiode zu verwenden, die Licht bekannter und konstanter Frequenz ausstrahlt.

Bedingt durch den Aufbau der Laserdiode variiert deren Frequenz bei Änderung der ihr zugeführten Stromstärke oder der Temperatur der laseraktiven Zone. Die Änderung der Stromstärke bewirkt hauptsächlich, infolge von Verlustwärme, eine Temperaturänderung der laseraktiven Zone. Es erweist sich daher als notwendig, die Temperatur der laseraktiven Zone, zumindest während der Längenmessung, konstant zu halten.

Aus dem Artikel "Emission Frequency Stability in Single-Mode-Fibre Optical Feedback Controlled Semiconductor Lasers", Electronics Letters, Vol. 19, No 17, August 1983, von F. Fouvre und D. Le Guen ist ein Verfahren entsprechend dem Oberbegriff des Anspruchs 1 bekannt.

Bei diesen Verfahren wird das Gehäuse der Laserdiode auf konstanter Temperatur gehalten und zwar unabhängig von der der Laserdiode zugeführten Stromstärke. Nachteilig ist, daß beim Einschalten des Stromes der Laserdiode infolge der dadurch auftretenden Verlustwärme, wie bereits oben beschrieben, eine Frequenzän-

derung des Lichts der Laserdiode auftritt und die Frequenz des Lichts der Laserdiode solange variiert, bis die Kühlung des Gehäuses der Laserdiode die durch den Strom hervorgerufene Erwärmung der laseraktiven Zone kompensiert hat. Die letztlich vorhandene Frequenz des Lichts der Laserdiode ist bei diesem Verfahren nur in relativ großen Grenzen vorhersagbar, da die Kurve der Frequenz der Laserdiode über der Temperatur unstetig ist, in Form einer Treppenfunktion verläuft und eine Hysterese besitzt. Damit sind der Genauigkeit der Längenmessung enge Grenzen gesetzt. Der relative Fehler der Frequenz beträgt:
$\Delta\nu/\nu = 10^{-3}$ mit $\nu[s^{-1}]$ Frequenz des Lichts der Laserdiode.

Weiterhin ist es bekannt, für Längenmessungen Helium-Neon-Laser einzusetzen. Dieser Laser bieten den Vorteil, daß sich die Frequenz des Laserlichts über eine Naturkonstante ermitteln läßt und konstant ist. Nachteilig jedoch ist, daß diese Helium-Neon-Laser vergleichsweise groß sind und so für viele Anwendungsgebiete, wo es auf kleine Bauweise ankommt, beispielsweise bei dem Einbau in NC-gesteuerten Werkzeug und Koordinatenme-maschinen nicht einsetzbar sind.

Weiterhin nachteilig sind die Helium-Neon-Laser im Vergleich zu einer Laserdiode wesentlich teurer, wodurch ebenfalls der Einsatz der Helium-Neon-Laser beschränkt wird.

Aus dem Aufsatz "Frequency Stabilisation of Semiconductor Lasers for Heterodyne-Type Optical Communication Systems", von T. Okoshi und K. Kikuchi, Electronics Letters, Vol. 16, No. 5, February 1980, ist ein Verfahren bekannt, welches nach Einregelung der Betriebsbedingungen der Laserdiode Frequenzschwankungen, die durch Temperatur- oder Spannungsschwankungen hervorgerufen werden, unterdrückt. Das Licht der Laserdiode wird dafür in zwei Meßpfade aufgespalten. Im ersten Meßpfad wird das Licht der Laserdiode direkt von einer Photodiode aufgenommen, im zweiten Meßpfad wird das Licht der Laserdiode über einen Fabry-Perot Interferometer einer zweiten Photodiode zugeführt. Die Ausgänge beider Photodioden sind mit einem Differentialverstärker verbunden, dessen Ausgang wiederum zur Steuerung der Wärmezu- oder -abfuhr benutzt wird. Nachteilig ist, daß diese Frequenzstabilisierung erst nach Einregelung des Betriebszustandes der Laserdiode, also nachdem die Laserdiode bereits Licht bestimmter Frequenz emittiert, zur Anwendung kommt. Beim Einschalten und Hochregeln des Stromes der Laserdiode variiert bei diesem Verfahren die Frequenz des Lichtes der Laserdiode, was die oben bereits beschriebenen Nachteile mit sich bringt. Weiterhin erfordert dieses Verfahren einen relativ großen apparativen Aufbau und ist dadurch bedingt teuer und auf Anwendungsgebiete beschränkt, bei denen für den Aufbau genügend Platz vorhanden ist.

Das Ausgangssignal des Differentialverstärkers kann anstatt zur Regelung der Wärmezu- oder -abfuhr zur Regelung der der Laserdioden zugeführten Stromstärke benutzt werden. Dies wird in dem Artikel "High Frequency Stability of Laserdiode for Heterodyne Communication Systems", F. Favre, D. Le Guen, Electronic Letters, Vol. 16, No. 18, August 1980, vorgeschlagen. Auch hier wird die Frequenz des Lichts der Laserdiode erst dann stabilisiert, wenn die Laserdiode bereits ihren Betriebszustand erreicht hat. Die oben bereits geschilderten Nachteile gelten hier entsprechend.

Eine Vorrichtung zur Stabilisierung der Frequenz einer Laserdiode entsprechend den Merkmalen des Oberbegriffs des Anspruchs 5 ist aus dem Bericht der physikalisch-technischen Bundesanstalt, "Temperaturstabilisierter, abstimmbarer und modulierter Diodenlaser", von A. Abou-Zeid und G. Leppelt, PTB-ME-67, April 1985, ISSN 0341-6720, bekannt. Es ist ein Temperaturregler vorgesehen, der das Gehäuse der Laserdiode auf konstante Temperatur hält. Die der Laserdiode zugeführte Stromstärke wird von einem Anfangswert, nämlich Null, auf einem Sollwert, die einem Sollwertgeber vorgegeben wurden, mittels eines Stromreglers hochgeregelt. Dabei wird insbesondere die Temperatur der laseraktiven Zone verändert, was eine Änderung der Frequenz des Lichts der Laserdiode zur Folge hat. Nach einer bestimmten Zeit macht sich die Temperaturänderung der laseraktiven Zone als Temperaturänderung am Gehäuse der Laserdiode bemerkbar, woraufhin der Temperaturregler eine Wärmezu- oder -abfuhr an dem Gehäuse der Laserdiode bewirkt, die sich wiederum nach einer gewissen Zeitspanne in der aktiven Zone der Laserdiode bemerkbar macht. Die Frequenz des Lichts der Laserdiode variiert dabei bei jeder Temperaturänderung der laseraktiven Zone.

Der Erfindung liegt die Aufgabe zugrunde, ein Verfahren und eine Vorrichtung zur Stabilisierung der Frequenz einer Laserdiode der eingangsbeschriebenen Art so weiter zu bilden, daß die Frequenzstabilisierung einer Laserdiode mit einer Langzeitstabilität von $\Delta\nu/\nu \leq 10^{-5}$ erfolgt, und bei vorzugsweiser Benutzung in der Längenmeßtechnik die relative Genauigkeit der gemessenen Länge $\Delta s/s \leq 10^{-6}$ beträgt, mit s [m] Länge.

Erfindungsgemäß wird dies bei dem Verfahren der eingangs genannten Art dadurch erreicht, daß die Stromstärke langsam von einem Anfangswert — insbesondere Null — auf einen Sollwert entsprechend der gewünschten Ausgangsleistung der Laserdiode gesteigert wird und dabei, sowie ggf. bei weiteren Veränderungen der Stromstärke, die Temperatur des Gehäuses der Laserdiode so verändert wird, daß die Temperatur der laseraktiven Zone der Laserdiode entsprechend einem Stabilitätsfaktor

$$\alpha = \frac{d\lambda}{di} \Big/ \frac{d\lambda}{dT}$$

konstant gehalten wird. Bei erfindungsgemäßer Anwendung des Verfahrens weist das Licht der Laserdiode eine stets gleichbleibende Frequenz auf, unabhängig der der Laserdiode zugeführten Stromstärke. Die Kompensation der Temperaturänderungen der laseraktiven Zone, hervorgerufen durch die Stromstärkeänderungen, erfolgt mittels Wärmezu- oder -abfuhr an dem Gehäuse der Laserdiode kontinuierlich in Abhängigkeit der der Laserdiode zugeführten Stromstärke. Die Wärmezu- oder -abfuhr, bzw. die Regelung der Stromstärke, erfolgt entsprechend einem Stabilitätsfaktor. Dieser Stabilitätsfaktor berücksichtigt einerseits den Wärmeübergang zwischen dem Gehäuse der Laserdiode und der laseraktiven Zone der Laserdiode und andererseits die Änderung der Frequenz des Lichtes der Laserdiode in Abhängigkeit von der Temperatur der laseraktiven Zone der Laserdiode. Anschaulich läßt sich das Verfahren mittels eines Diagrammes erklären, bei dem die der Laserdiode zugeführte Stromstärke über der Temperatur des Gehäuses der Laserdiode aufgetragen ist (Fig. 3). Für konstante Frequenzen des Lichts der Laserdiode ergeben sich in diesem Diagramm Graden mit negativen Steigungen. Wird nun die Stromstärke verändert, sei es um die Laserdiode einzuschalten oder durch

Spannungsschwankungen im Netz, wird die Temperatur der laseraktiven Zone durch Wärmezu- oder -abfuhr an dem Gehäuse der Laserdiode entsprechend der Geraden in dem Diagramm Stromstärke über Temperatur des Gehäuses der Laserdiode für eine bestimmte Frequenz verschoben. Vorteilhaft wird damit erreicht, daß die Frequenz des Lichtes der Laserdiode in jedem Betriebszustand, also insbesondere auch bei den Messungen, konstant gehalten wird.

Weiterhin vorteilhaft ist, daß die Frequenz des Lichtes der Laserdiode von vorneherein sehr genau bekannt ist, da die bekannten Sprung- und Hystereseeffekte der Laserdiode bei diesem Verfahren nicht auftreten können. Dies ist damit zu erklären, daß die laseraktive Zone der Laserdiode stets auf konstante Temperatur gehalten wird.

Vorteilhaft wird mit diesem Verfahren zur Stabilisierung der Frequenz einer Laserdiode eine Langzeitkonstanz der einmal eingestellten Frequenz über mindestens mehrere Monate erreicht. Es sind somit keine aufwändigen Nacheichungen und Kontrollmaßnahmen erforderlich. Weiterhin kann vorteilhaft die Eichung der Laserdiode, also die Ermittlung des Stabilitätsfaktors, werksseitig vorgenommen und als Gerätefaktor der Laserdiode angegeben werden.

Durch die zuverlässige Stabilisierung der Frequenz der Laserdiode kann sie in vielen Anwendungsgebieten, die ihr vorher verschlossen blieben, eingesetzt werden. Der Vorteil solch einer Laserdiode, im Vergleich zu den sonst üblichen Helium-Neon-Lasern, liegt sowohl in der kompakten Bauweise, als auch im geringen Anschaffungspreis. Weiterhin arbeitet eine Laserdiode hochspannungsfrei, hat eine hohe Ausgangsleistung und nur geringe Wärmeverluste sowie eine hohe Lebensdauer.

Vorteilhaft kann bei Anwendung des oben beschriebenen Verfahrens eine bestimmte, vorgewählte Frequenz des Lichtes der Laserdiode eingestellt werden. Es können alle Frequenzen gewählt werden, die zwischen den Frequenzsprüngen der Funktion in dem Diagramm Frequenz des Lichtes der Laserdiode über der Temperatur der laseraktiven Zone der Laserdiode liegen.

Die Intensität des Lichtes der Laserdiode kann vorteilhaft durch Änderung der der Laserdiode zugeführten Stromstärke variiert werden, ohne das sich eine Frequenzverschiebung des Lichtes der Laserdiode ergibt. Verfahrensgemäß wird dann dabei die Temperatur des Gehäuses der Laserdiode derart nachgeregelt, daß die Temperatur der laseraktiven Zone der Laserdiode wiederum konstant bleibt.

Vorteilhaft kann die Temperatur der laseraktiven Zone der Laserdiode auch dann konstant gehalten werden, wenn die Stromstärke auf einen Anfangswert — insbesondere Null — erniedrigt wird. Das heißt also, daß die die Regelung der Wärmezu- oder -abfuhr auch dann aktiv bleibt, wenn die Laserdiode selbst nicht betrieben wird. Temperaturschwankungen an dem Gehäuse der Laserdiode, hervorgerufen durch beispielsweise Änderung der Umgebungstemperatur, werden ausgeglichen und die Temperatur der laseraktiven Zone der Laserdiode bleibt konstant. Dadurch entstehen bei Inbetriebnahme der Laserdiode praktisch keinerlei Anlaufzeiten und die Laserdiode ist sofort betriebsbereit.

Vorteilhaft kann zum Zwecke der Kalibrierung die Abhängigkeit der Wellenlänge von der Stromstärke einerseits und der Temperatur andererseits gemessen, die Steigungen der Kurven der Wellenlänge über der Stromstärke bei konstanter Temperatur und der Wellenlänge über der Temperatur bei konstanter Stromstärke aus diesen Messungen ermittelt und durch Quotientenbildung dieser Steigungen der Stabilitätsfaktor α errechnet werden, nach welchem die Temperatur der laseraktiven Zone der Laserdiode konstant gehalten wird. Durch die Bildung eines Stabilitätsfaktors kann für jede, sich individuell verhaltene Laserdiode, mit nur einem Wert dem Anwender mitgeteilt werden, wie er die verfahrensmäßig durchzuführende Regelung an die individuelle Laserdiode anpassen muß. Die Ermittlung der Steigungen der Kurven der Frequenz des Lichtes der Laserdiode über der Stromstärke bei konstanter Temperatur der laseraktiven Zone der Laserdiode und der Frequenz der Lichtes der Laserdiode zu der Temperatur der laseraktiven Zone der Laserdiode bei konstanter Stromstärke durch Messung hat sich als einfach und sehr genau erwiesen. Der Wärmeübergang zwischen dem Gehäuse der Laserdiode und der laseraktiven Zone der Laserdiode, der mathematisch kaum oder nur mit erheblichem Aufwand berechenbar ist, wird durch die Messung automatisch erfaßt.

Vorteilhaft kann als Temperatur des Gehäuses der Laserdiode zu Beginn des Einschaltens des Stromes diejenige Temperatur benutzt werden, bei der auch der Stabilitätsfaktor ermittelt wurde. Damit wird mit sehr hoher Genauigkeit diejenige Frequenz des Lichtes der Laserdiode erreicht, die vorher eingestellt wurde. Bei Einsatz der Laserdiode in der Längenmeßtechnik kann somit ein relativer Meßfehler erreicht werden, der kleiner als 10^{-6} m/m ist, oder mathematisch ausgedrückt: $\Delta s/s \leq 10^{-6}$.

Die Stabilisierung der Frequenz des Lichts der Laserdiode, unabhängig von jeglichen Änderungen der der Laserdiode zugeführten Stromstärke, wird bei der Vorrichtung erfindungsgemäß dadurch erreicht, daß ein Kopplungsglied vorgesehen ist, daß dem Kopplungsglied die Ist-Größen des Stromreglers und des Temperaturreglers zugeführt werden, daß das Kopplungsglied entsprechend einem funktionalen Zusammenhang zwischen Stromstärke und Temperatur für konstante Wellenlänge der Laserdiode Führungsgrößen an den Stromregler und dem Temperaturregler derart anlegt, daß die Frequenz der Laserdiode konstant bleibt. Damit werden vorteilhaft die aus dem Stand der Technik bekannten und oben beschriebenen Nachteile vermieden. Diese und weitere Vorteile ergeben sich aus den Unteransprüchen und dem Ausführungsbeispiel.

Die Erfindung wird anhand bevorzugter Ausführungsbeispiele weiter beschrieben. Es zeigt

Fig. 1 ein Diagramm der Wellenlänge des Lichts der Laserdiode über die Stromstärke;

Fig. 2 ein Diagramm der Wellenlänge des Lichts der Laserdiode über der Temperatur des Gehäuses der Laserdiode;

Fig. 3 ein Diagramm der Stromstärke über die Temperatur des Gehäuses der Laserdiode für verschiedene Frequenzen des Lichts der Laserdiode;

Fig. 4 ein Diagramm der Stromstärke über der Zeit;

Fig. 5 ein Diagramm der Temperatur des Gehäuses der Laserdiode über die Zeit;

Fig. 6 ein Diagramm der Temperatur der laseraktiven Zone und der Frequenz der Wellenlänge des Lichts der Laserdiode über die Zeit;

Fig. 7 ein Blockdiagramm einer ersten Ausführungsform der erfindungsgemäßen Vorrichtung;

Fig. 8 ein Blockdiagramm einer zweiten Ausführungsform der erfindungsgemäßen Vorrichtung.

Fig. 1 zeigt die Wellenlänge des emittierten Lichtes der Laserdiode über der der Laserdiode zugeführten

Stromstärke bei konstanter Temperatur der laseraktiven Zone. Es ergibt sich eine Treppenfunktion. Bei einigen Werten der der Laserdiode zugeführten Stromstärke ergeben sich Unstetigkeiten, zwischen denen die Funktion einen linearen Verlauf mit positiven Gradienten aufweist. Sowohl die Gradienten der geraden Stücke der Treppenfunktion als auch die Lage der Unstetigkeitsstellen sind für verschiedene Laserdioden unterschiedlich. Zur Ermittlung des Stabilitätsfaktors wird für jede einzelne Laserdiode individuell dieser funktionale Zusammenhang durch Messung bestimmt. Es hat sich gezeigt, daß der individuelle Verlauf der Frequenz des emittierten Lichts der Laserdiode über der der Laserdiode zugeführten Stromstärke reproduzierbar ist, so daß diese Messung, die einen bestimmten apparativen Aufbau voraussetzt, werksseitig durchgeführt werden kann.

Fig. 2 zeigt die Wellenlänge des emittierten Lichts der Laserdiode über der Temperatur des Gehäuses der Laserdiode bei konstanter Stromstärke der Laserdiode. Der funktionale Zusammenhang ergibt sich wiederum als eine Treppenfunktion. Die Steigungen zwischen den Unstetigkeitsstellen sind positiv. Dieser funktionale Zusammenhang ist ebenfalls für jede Laserdiode individuell zu ermitteln, dann aber reproduzierbar. Somit kann auch diese Messung werksseitig durchgeführt werden. Mit Hilfe der beiden Steigungen $d\lambda/di$, $d\lambda/dT$ läßt sich der Stabilitätsfaktor α durch Quotientenbildung errechnen. Für jeweils konstante Frequenzen des emittierten Lichts der Laserdiode ergibt sich daraus die Abhängigkeit der Temperatur des Gehäuses der Laserdiode von der der Laserdiode zugeführten Stromstärke, (**Fig.** 3). Jeder funktionale Zusammenhang stellt sich für konstante Frequenz des emittierten Lichts der Laserdiode als Gerade mit negativen Gradienten dar. Bei erfindungsgemäßer Anwendung des Verfahrens wird bei jeder Änderung der Laserdiode zugeführten Stromstärke die Temperatur des Gehäuses der Laserdiode derart nachgeregelt, daß der Schnittpunkt zwischen der der Laserdiode zugeführten Stromstärke und der Temperatur des Gehäuses der Laserdiode in dem Diagramm stets auf ein und derselben Geraden liegt. Damit ist gewährleistet, daß bei jeglichen Änderungen der der Laserdiode zugeführten Stromstärke die Frequenz des emittierten Lichtes der Laserdiode stets konstant ist. Ebenso können natürlich auch Änderungen der Temperatur des Gehäuses der Laserdiode durch entsprechende Änderungen der der Laserdiode zugeführte Stromstärke kompensiert werden. Wichtig ist nur, daß der Schnittpunkt beider Größen immer auf ein und derselben Geraden für die gewünschte Frequenz des Lichtes der Laserdiode liegen.

Fig. 4 zeigt die Zeitabhängigkeit der der Laserdiode zugeführten Stromstärke. Bei aus dem Stand der Technik bekannten Verfahren wird die Stromstärke, wie die gestrichelte Line zeigt, relativ schnell von einem Anfangswert, beispielsweise Null, auf einen Sollwert erhöht. Die durchgezogene Linie zeigt die Erhöhung der der Laserdiode zugeführten Stromstärke bei Anwendung des erfindungsgemäßen Verfahrens. Die Stromstärke wird von einem Anfangswert wesentlich langsamer auf einen Sollwert erhöht. Die Änderung der Stromstärke erfolgt entsprechend dem vorher berechneten Leistungsfaktor. Der hier dargestellte Kurvenverlauf ist natürlich nur qualitativ zu verstehen, da die Änderung der Stromstärke nach einem, für jede Laserdiode individuellen, Stabilitätsfaktor bestimmt wird, und somit auch von der individuellen Ausführung des Gehäuses der Laserdiode abhängig ist.

Fig. 5 zeigt den Verlauf der Temperatur des Gehäuses der Laserdiode über der Zeit. Die gestrichelte Linie gibt die Verhältnisse bei dem aus dem Stand der Technik bekannten Verfahren wieder. Nach einer gewissen Ansprechzeit erhöht sich die Temperatur des Gehäuses der Laserdiode. Dies wird registriert und durch Wärmeabfuhr des Gehäuses der Laserdiode über die Temperatur des Gehäuses der Laserdiode innerhalb gewisser Grenzen konstant gehalten. Dadurch ergibt sich ein Einschwingvorgang, wie er schematisch in **Fig.** 5 dargestellt ist. Bei der erfindungsgemäßen Anwendung des Verfahrens dagegen wird die Temperatur des Gehäuses der Laserdiode kontinuierlich, in Abhängigkeit der Änderungen der der Laserdiode zugeführten Stromstärke, erniedrigt.

Fig. 6 demonstriert deutlich die Vorteile des erfindungsgemäßen Verfahrens. Dort sind die Temperaturen der laseraktiven Zone der Laserdiode und die Wellenlänge des emittierten Lichtes der Laserdiode über die Zeit aufgetragen. Bei dem erfindungsgemäßen Verfahren sind sowohl die Temperatur der laseraktiven Zone als auch die Wellenlänge des emittierten Lichtes der Laserdiode konstant. Anders dagegen verhält es sich bei Verfahren aus dem Stand der Technik, wie dies die gestrichelten Linien zeigen. Die Temperatur der laseraktiven Zone steigt, bedingt durch die Erhöhung der der Laserdiode zugeführten Stromstärke, an. Aufgrund der Wärmeabfuhr des Gehäuses der Laserdiode wiederum ab bis sie, nach einem Einschwingvorgang, einen konstanten Wert erhält. Die Frequenz des emittierten Lichtes über der Zeit weist einen unstetigen und ungeordneten Verlauf auf. Dieser Kurvenverlauf ist nicht vorhersehbar und nicht reproduzierbar, da er sich aus einer Überlagerung der Kurvenverläufe entsprechend **Fig.** 1 und **Fig.** 2 zusammensetzt und weiterhin starke Hystereseeffekte auftreten.

Fig. 7 zeigt eine erste Version der Vorrichtung zur Stabilisierung der Frequenz einer Laserdiode. Eine Spannungsquelle **1** ist mit einem Sollwertgeber **2** verbunden. Der Ausgang des Sollwertgebers **2** liegt an einem Stromregler **3**. Der Stromregler **3** besitzt zwei Ausgänge **4** und **5** und zwei Eingänge **6** und **7**. Am Ausgang **4** ist eine Laserdiode **8** angeschlossen, am Ausgang **5** ein Kopplungsglied **9**. Am Eingang **7** liegt der Ist-Wert der Stromstärke an, am Eingang **6** eine Führungsgröße **10**, die vom Kopplungsglied **9** zur Verfügung gestellt wird. Weiterhin ist ein Temperaturregler **11** vorgesehen, an dem die Ist- Temperatur **12** des Gehäuses der Laserdiode **8** an einem Eingang **13** und eine Führungsgröße **14** des Kopplungsgliedes **9** an einem Eingang **15** anliegt. Ein Eingang **16** dient zur Aufnahme einer Soll-Temperatur **17**. Weiterhin besitzt der Temperaturregler **11** zwei Ausgänge **18** und **19**. Der Ausgang **18** ist mit dem Kopplungsglied **9** verbunden, der Ausgang **19** mit einem Peltierelement **20**.

Die Ist-Temperatur **12** des Gehäuses der Laserdiode **8** wird gemessen und dem Temperaturregler **11** zugeführt. Der Temperaturregler **11** hält die Ist-Temperatur **12** des Gehäuses der Laserdiode **8** konstant, solange keine Führungsgröße **14** am Eingang **15** des Temperaturreglers **11** anliegt. Der Strom der Laserdiode **8** wird durch den Stromregler **3** geregelt. Der Ist-Wert des Stromes wird dem Stromregler **3** am Eingang **7** zugeführt. Der Soll-Wert des Stromes wird mit dem Sollwertgeber **2** eingestellt. Die Führungsgrößen **10** und **14** werden von dem Kopplungsglied **9** erzeugt. Beim Einschalten der Laserdiode **8** wird dem Sollwertgeber **2** der

gewünschte Wert des Stromes vorgegeben. Der Stromregler 3 erhöht die der Laserdiode **8** zugeführte Stromstärke und gibt ein entsprechendes Signal an das Kopplungsglied **9**. Das Kopplungsglied **9** legt Führungsgrößen **10** und **14** an den Stromregler 3 und dem Temperaturregler **11** an. Diese Führungsgrößen **10** und **14** veranlassen den Stromregler 3 und den Temperaturregler **11** derart miteinander zu wirken, daß die über die Ausgänge **4** und **19** mit der Laserdiode **8** verbundenen Größen sich entsprechend dem Stabilitätsfaktor α verhalten.

Fig. 8 zeigt eine zweite Version der Vorrichtung zur Stabilisierung der Frequenz einer Laserdiode. Die Laserdiode **8** ist mit einem Mikroprozessor **21** verbunden. Der Mikroprozessor **21** besitzt einen Eingang **22** und zwei Ausgänge **23** und **24**. Am Eingang **22** des Mikroprozessors **21** liegt die Ist-Temperatur **12** des Gehäuses der Laserdiode **8** an. Diese wird einem A/D-Wandler **25** zugeführt. Ein D/A-Wandler **26** legt ein analoges Signal an den Ausgang **23**, der mit dem Peltierelement **20** der Laserdiode **8** verbunden ist. Ein weiterer D/A-Wandler **27** ist mit dem Ausgang **24**, von dem aus die Speisung der Laserdiode **8** mit Strom erfolgt, und einem Eingang eines A/D-Wandlers **28** verbunden.

Die zweite Ausführungsform unterscheidet sich von der ersten Ausführungsform dadurch, daß die Steuerung der Laserdiode im Bezug auf Strom und Temperatur jetzt von einem Mikroprozessor **21** übernommen wird. Die Ist-Temperatur **12** der Laserdiode **8** wird dem A/D-Wandler **25** zugeführt. Die Digitalinformation der Temperatur **12** wird sodann dem Mikroprozessor **21** zugänglich gemacht. Der Sollwert des Stromes und der Stabilitätsfaktor kann in den Mikroprozessor **21** fest einprogrammiert sein oder über externe Tastenfelder **29** eingebbar sein. Der Mikroprozessor **21** übernimmt dann die Regelung der der Laserdiode **8** zugeführten Stromstärke und Temperatur entsprechend dem Stabilitätsfaktor.

Bezugszeichenliste

1 = Spannungsquelle
2 = Sollwertgeber
3 = Stromregler
4 = Ausgang
5 = Ausgang
6 = Eingang
7 = Eingang
8 = Laserdiode
9 = Kopplungsglied
10 = Führungsgröße
11 = Temperaturregler
12 = Ist-Temperatur
13 = Eingang
14 = Führungsgröße
15 = Eingang
16 = Eingang
17 = Solltemperatur
18 = Ausgang
19 = Ausgang
20 = Peltierelement
21 = Mikroprozessor
22 = Eingang
23 = Ausgang
24 = Ausgang
25 = A/D-Wandler
26 = D/A-Wandler
27 = D/A-Wandler
28 = A/D-Wandler
29 = Tastenfeld

Fig. : 19 : 14

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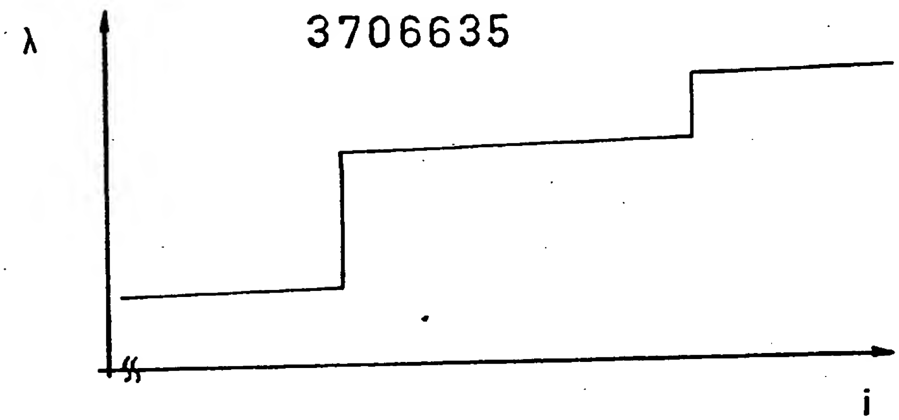

Fig. 1

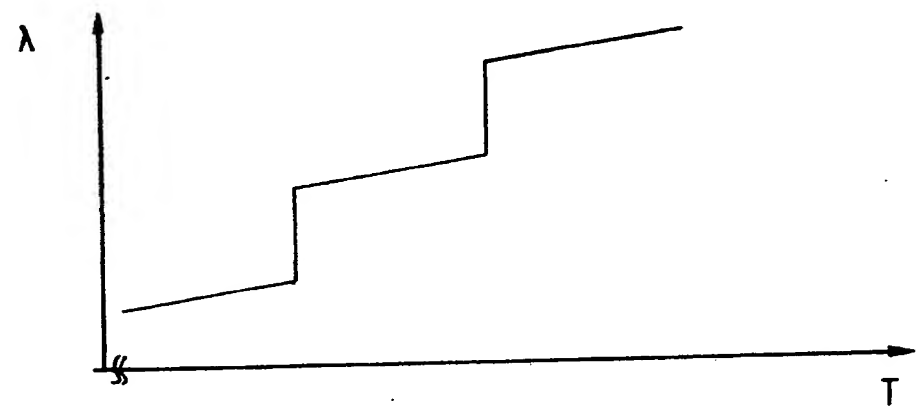

Fig. 2

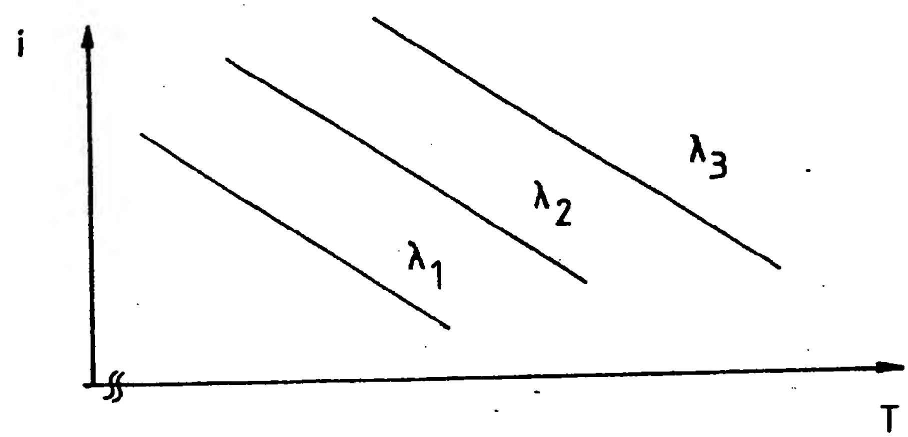

Fig. 3

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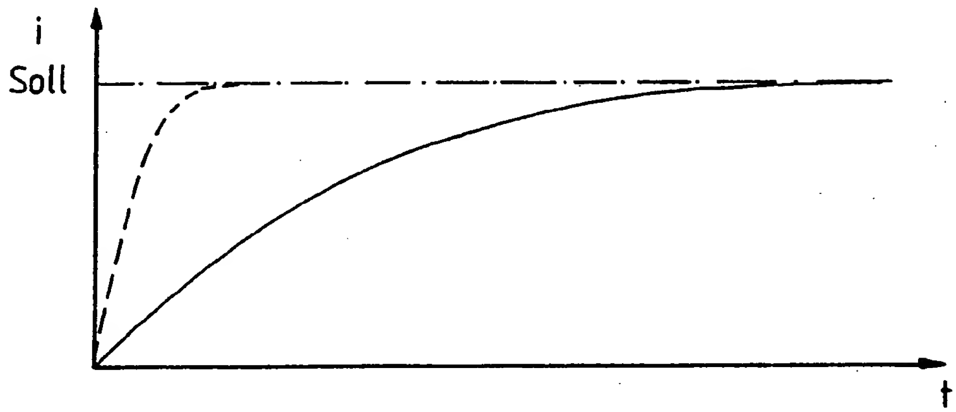

Fig. 4

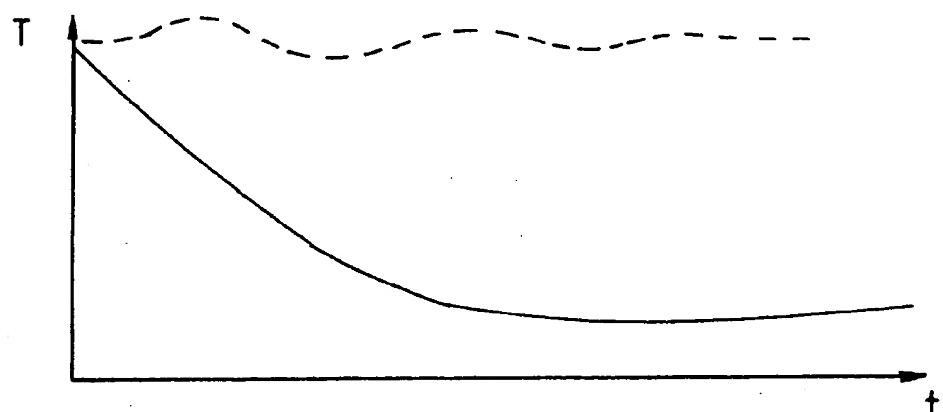

Fig. 5

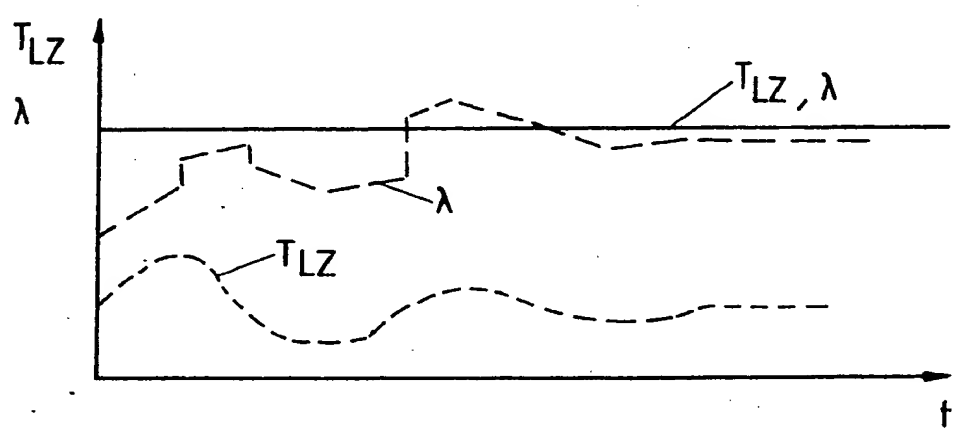

Fig. 6

Fig. : 21 ; 11

21

3/4

3706635

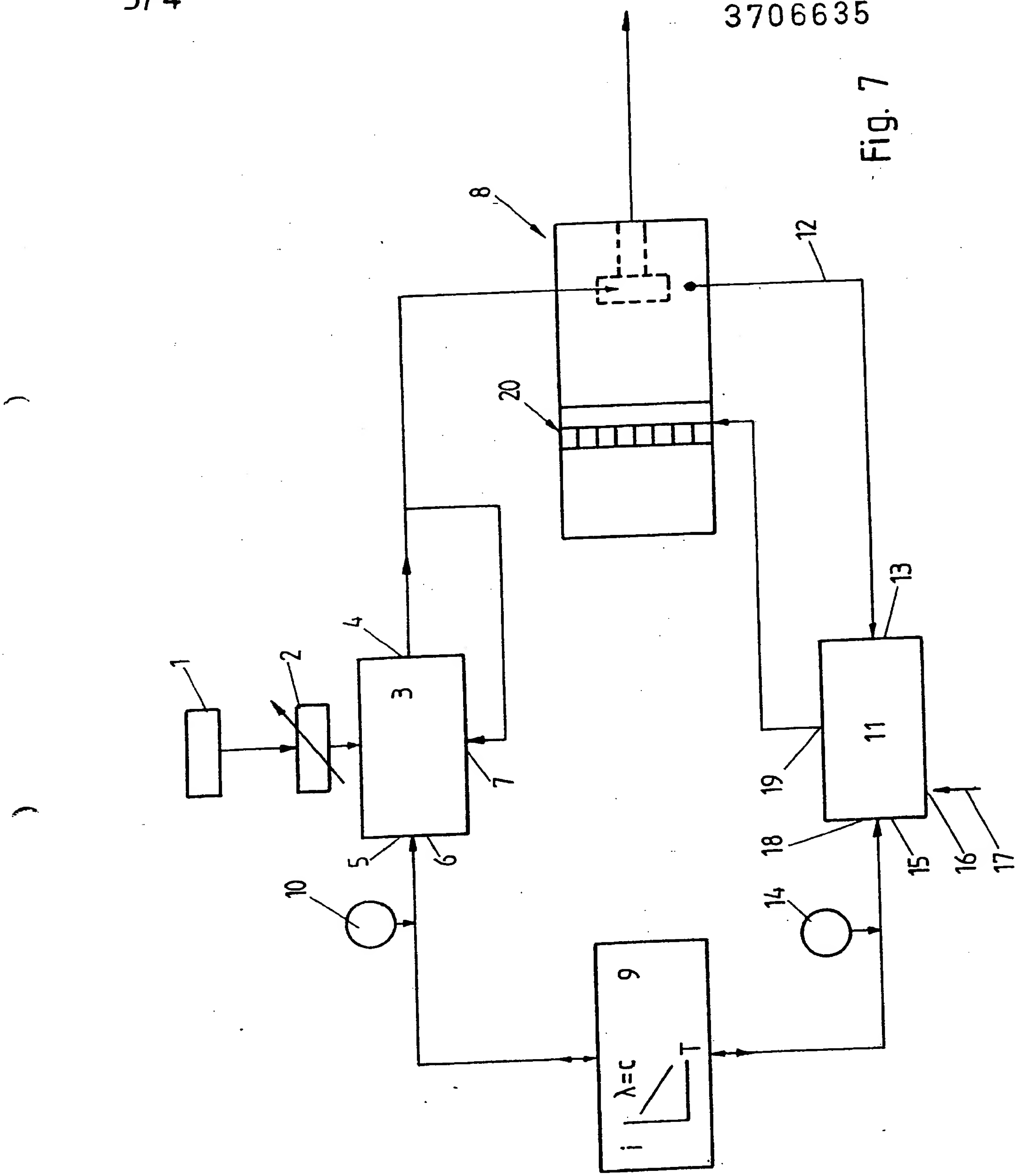

Fig. 7

3706635

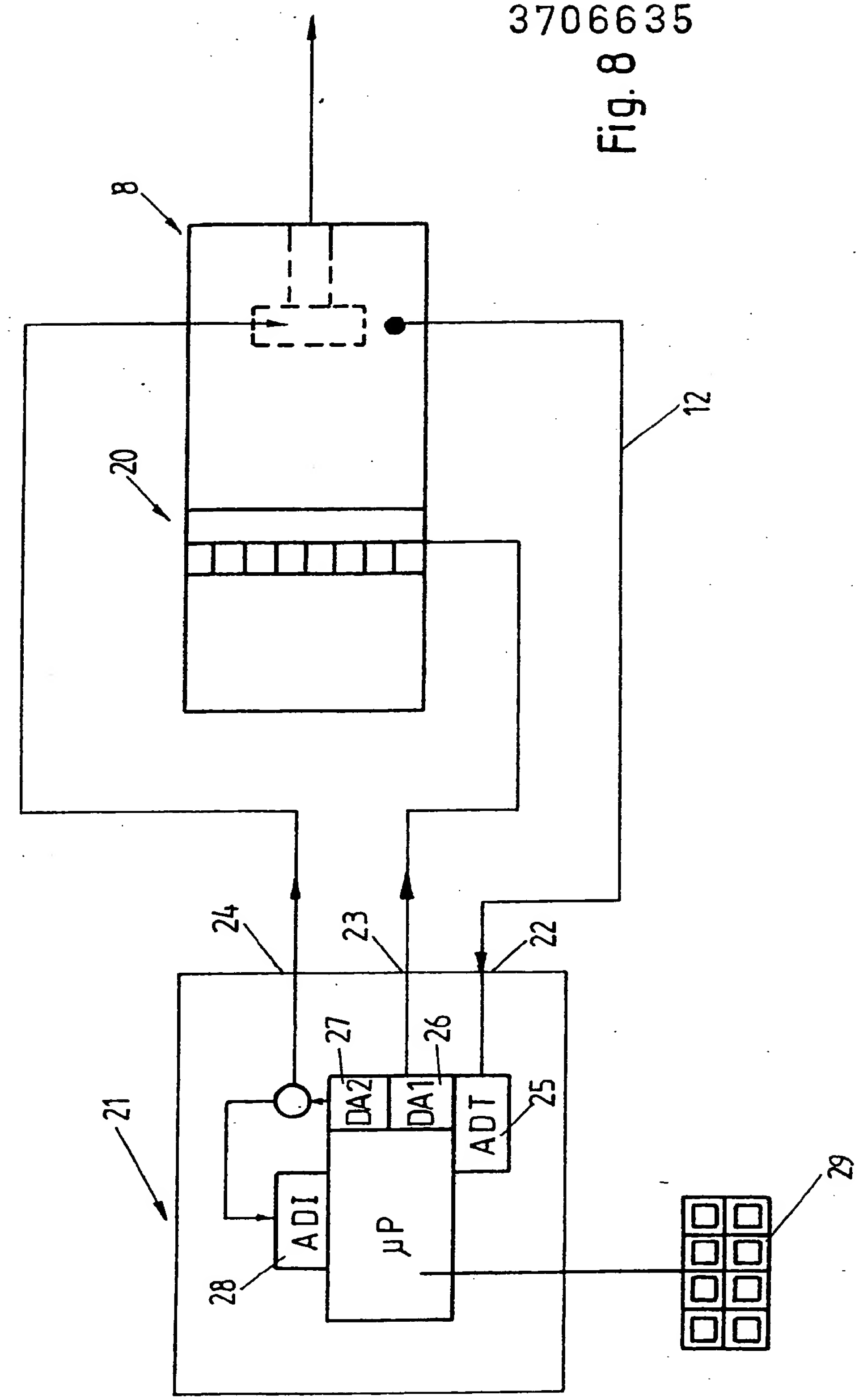

Fig. 8

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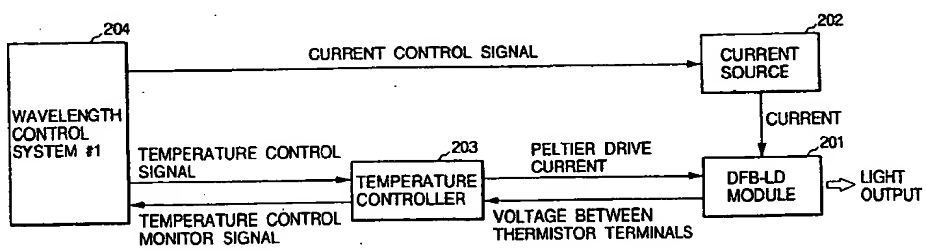
(54) **Wavelength-changeable light source capable of changing wavelength of output light, optical communication network using the same and wavelength control method for controlling wavelength of output light of the same**

(57) In a wavelength-changeable light source of the present invention, a wavelength control is performed using a plurality of control systems when the wavelength of a laser, particularly a semiconductor laser, is to be controlled. Wavelength control characteristics of the respective control systems are different from each other, and the wavelength control can be flexibly carried out by combining those characteristics. Specifically, one of the plural control systems is a current control unit for controlling a current supplied to the semiconductor laser and another thereof is a temperature control unit for controlling temperature of the semiconductor laser. In the structure, the wavelength shift with a speedy response time, which can be attained in a wavelength-changeable range obtainable by the current control, can be carried out over a wide wavelength-changeable range obtainable by the temperature control.

FIG. 2



EP 0 813 272 A2

Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a wavelength-changeable or tunable light source using a laser, and particularly to a wavelength-changeable or tunable light source using a semiconductor laser (hereinafter also referred to as LD), an optical communication network using the light source and a wavelength control method for controlling the wavelength of output light from the light source.

Related Background Art

Study and development of a wavelength-changeable light source have been increasingly advanced as an important key device in the fields of wavelength division multiplexing communications, optical measurements and so forth. For example, study and development of a single-wavelength operative LD, such as a distributed feedback laser diode (DFB-LD) and a distributed Bragg reflector laser diode (DBR-LD), have been promoted. An example thereof will hereinafter be described.

Fig. 7 is a block diagram illustrating a wavelength-changeable light source using a two-electrode DFB-LD. The light source includes a two-electrode DFB-LD module 701, a two-output current source 702, a temperature controller 203 and a wavelength control system #4 (703).

The two-electrode DFB-LD module 701 is a device in which its current-injection electrode is divided into two portions and the wavelength of its light output can be changed by controlling a current injected into the device. An example thereof is disclosed in "Journal of Electronics Letters, volume 22, No. 22, pp. 1153-1154". In this example, the lasing wavelength is in a range of 1556 nm to 1558 nm and thus a wavelength-changeable range of about 2 nm is attained. Further, some manufacturers presently sell such a device as a module for the use of study. The two-electrode DFB-LD module 701 is constructed by packaging the above two-electrode DFB-LD together with an optical coupling system, an optical isolator, an optical fiber, a Peltier element, a thermistor and so forth. Since the lasing wavelength of the two-electrode DFB-LD shifts due to a change in its ambient or environmental temperature, the device temperature of the two-electrode DFB-LD is controlled by the Peltier element and the thermistor and thus a change in the lasing wavelength due to the temperature change is controlled. The optical isolator prevents the return of light into the two-electrode DFB-LD, and hence stabilizes the lasing wavelength of the two-electrode DFB-LD.

Further, the two-output current source 702 is an electric current source which has two independent outputs. The output currents of the current source 702 are set by a current control signal input from its outside (i.e., from the wavelength control system #4). The temperature controller 203 causes a current to flow into the thermistor (which is arranged in the two-electrode DFB-LD module) and measures the temperature by detecting a voltage between the thermistor terminals. The temperature controller 203 further drives the Peltier element (which is also arranged in the two-electrode DFB-LD module) having heat-generation and heat-absorption characteristics due to a current injected thereinto such that the measured temperature reaches a target temperature. The Peltier element can increase or decrease the temperature of a heat sink on which the two-electrode DFB-LD is mounted. The target temperature can be set in the temperature controller or by using a temperature control signal from its outside. Further, a difference between the target temperature and the measured temperature is output as a temperature control monitor signal. In this example, the target temperature is internally set. The wavelength control system #4 (703) controls the two-output electric current source 702 by using the current control signal, and controls the wavelength of the two-electrode DFB-LD module 701.

Fig. 8 illustrates another example of the wavelength-changeable light source using a DFB-LD. The light source is comprised of a single-electrode DFB-LD module 201, a current source 202, a temperature controller 203 and a wavelength control system #5 (801).

The single-electrode DFB-LD module 201 is a device that is presently sold commercially as a module by several manufacturers. Since the device only has a single electrode, its lasing wavelength can not be largely varied by a current injected thereinto. The ratio of a change in the lasing wavelength relative to the injected current is small, such as about 0.008 nm/mA, and the light output is also varied as the injected current increases. Therefore, the wavelength-changeable range due to the current is in the order of 0.1 nm. For this reason, the wavelength is changed by using a change in the temperature in this example. For instance, the ratio of a change in the wavelength relative to the temperature is about 0.08 nm/°C and thus the wavelength-changeable range in the order of nanometer can be obtained.

The DFB-LD module 201 is constructed by packaging the above DFB-LD together with the optical coupling system, the optical isolator, the optical fiber, the Peltier element, the thermistor and so forth. For example, in a DFB laser diode manufactured by Fujitsu Limited, FLD150F2KP (a trade name), its threshold current is 20 mA, its forward voltage 1.1 V (IF=30mA), a standard value of its peak lasing wavelength is 1550 nm and a maximum of its spectral half width is 0.2 nm. This is a light emitting device with a single mode fiber. The inventor of the present invention measured characteristics of that light emitting element, and obtained the characteristics shown in Figs. 9A and 9B. Fig. 9A shows the characteristic of the lasing wavelength relative to the temperature, and Fig. 9B shows the characteristic of the

lasing wavelength relative to a supplied current. It can be known from those measurement results that the wavelength can be varied in a range having a width of 2 nm by the temperature control between 15°C and 35°C and that the wavelength can be varied in a range having a width of 0.35 nm by the current control between 30 mA and 70 mA.

The current source 202 is a single-output current source. Its output current can be controlled by the internal setting or by the current control signal input thereinto from outside. In this example, the internal setting is performed. The temperature controller 203 is the same as illustrated in Fig. 7. In this example, the voltage between the thermistor terminals from the DFB-LD module 201 is detected by the temperature controller 203, and the temperature control monitor signal is recognized by the wavelength control system #5. In addition thereto, the wavelength control system #5 outputs the temperature control signal, by which the DFB-LD module 201 is set to a desired wavelength, on the basis of that temperature control monitor signal. Accordingly, the temperature setting is performed by controlling the temperature controller 203 using the temperature control signal from outside (i.e., from the wavelength control system #5). The wavelength control system #5 (801) thus controls the temperature controller 203 by using the temperature control signal, and controls the lasing wavelength of the DFB-LD module 201. On the other hand, the wavelength control system #5 (801) monitors the condition of the temperature control by using the temperature control monitor signal from the DFB-LD module 201.

The above-discussed wavelength-changeable light sources, however, have the following disadvantages.

The drawback of the example using the two-electrode DFB-LD will be initially described. This device has been only produced on trial, and its fabrication process for mass production has not yet been established and hence its cost is high. Situations of other multi-electrode wavelength-changeable LDs, such as three-electrode DFB-LDs and three-electrode DBR-LDs, are the same. Therefore, though those device have the wavelength-changeable range having a width of 2 nm, the supply of those devices having sufficiently stable characteristics is not yet achieved.

The drawback of the example using the temperature control will next be described. Generally, the response of a temperature control system is slow. The same is also true in the temperature control system of the LD module in which the temperature is detected by the thermistor and the temperature is controlled by the Peltier element. Specifically, it is difficult to settle its control within one second. Further, as the settling time of the control is shortened, overshooting is likely to occur. When such a device is used as a light source in wavelength division multiplexing communications with narrow intervals between channels, crosstalk is likely to occur during the time of changing the wavelength.

It is an object of the present invention to provide a wavelength-changeable or tunable light source in which a current control with a speedy response and a narrow wavelength-changeable range is combined with a temperature control with a slow response and a wide wavelength-changeable range, hence the wavelength-changeable range having a width in the order of nanometer is achieved even when a single-electrode DFB-LD is used and time required for the wavelength changing operation is shortened.

SUMMARY OF THE INVENTION

The inventor of the present invention described in the specification of this application conceived that it is possible to use the temperature control in, for example, a laser, which controls its lasing wavelength by the current control, not only for suppression of influences of a change in the ambient or environmental temperature due to heat generation in the laser and a change in the exterior temperature but also for a control of changing the lasing wavelength and that hence the wavelength control can be flexibly performed. According to one aspect of the present invention invented based on that conception, there is provided the following wavelength-changeable light source:

This wavelength-changeable light source includes a laser, a first control unit for continuously controlling a lasing wavelength of the laser with a short response time and a second control unit for continuously controlling the lasing wavelength of the laser with a response time which is longer than the response time of the wavelength control by the first control unit. The second control unit controls the lasing wavelength so as to change the lasing wavelength.

The response time in the present invention does not mean a time period during which an actual control is performed, but means a time period required for a control at the time when this control is executed by the control unit. Further, throughout the specification, a continuous control of the lasing wavelength or a continuous control by the control unit means not only a control in which the control value is exactly continuously changed, but also a control in which a series of changes in the control value are continued at minute steps (this minute step is a step with such a minute magnitude that even when the wavelength of light is changed at this minute step, a receiver side receiving the light can unceasingly continue reception of the light without any change or with a tracking operation being conducted).

In such a light source, the control can be performed using the first control unit where the lasing wavelength needs to be changed speedily, and the control can be performed using the second control unit where the lasing wavelength may be changed slowly. Particularly, in a case where a wavelength-changeable range by the control of the second control unit is wider than a wavelength-changeable range by the control of the first control unit, a light source with a wide wavelength-changeable range and a short response time for the wavelength change can be obtained.

The present invention can take a construction in which the second control unit performs such a control that the amount of a change in the lasing wavelength by the first control unit is replaced by the amount of a change in the lasing wavelength by the second control unit. Specifically, after the lasing wavelength is speedily changed, for example, to a longer wavelength side by the first control unit, the control of changing the lasing wavelength to a longer wavelength side is executed by the second control unit while the control of changing the wavelength to a longer wavelength side by the first control unit is relaxed. The control of changing the wavelength to a shorter wavelength side is effected similarly. With regard to the control in which the amount of a change in the wavelength effected by the first control unit is replaced by the amount of a change in the wavelength effected by the second control unit, it is not limited to a control in which the amount of a change in the wavelength by the first control unit is 100 % replaced by the amount of a change in the wavelength by the second control unit. The amount of a change in the wavelength by the second control unit may be larger or smaller than the amount of a change in the wavelength by the first control unit, depending on the situation. The former situation (a larger case) is, for example, a case where after the wavelength is promptly changed, the wavelength is further changed slowly to the same side. The latter situation (a smaller case) is, for example, a case where after the wavelength is promptly and sufficiently changed, an overshooting change in the lasing wavelength is returned to a target wavelength. In the case where the 100 % replacement is carried out and a rate of returning the wavelength control by the first control unit to its original state is the same as a rate of replacing the wavelength control by the first control unit with the wavelength control by the second control unit, the wavelength remains substantially unchanged throughout the replacement process though the control for changing the wavelength is performed by the second control unit. The present invention also includes those constructions discussed above.

Since after the lasing wavelength is changed by the first control unit, the amount of a change in the wavelength is replaced with the wavelength change conducted by the second control unit, a prompt response will be able to be done when there occurs a need to speedily change the lasing wavelength again.

The following more specific structures may also be adopted. The laser can be a semiconductor laser. The first control unit can be a current control unit for controlling a current supplied to the semiconductor laser. The second control unit can be a temperature control unit for controlling temperature of the semiconductor laser.

Various constructions can be employed as a structure for controlling the two control units, and such a structure can be constructed by using an analog operational or arithmetic circuit.

Further, a wavelength-placement detecting unit for detecting the placement condition of wavelengths on a transmission line, to which output light of the laser is output, can be provided, and the first control unit and the second control unit can perform their own controls on the basis of wavelength-placement information obtained from the wavelength-placement detecting unit, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a timing chart for controlling the lasing wavelength of a wavelength-changeable light source.

Fig. 2 is a view illustrating the structure of a first embodiment of a wavelength-changeable light source according to the present invention.

Fig. 3 is a view illustrating the structure of a second embodiment of a wavelength-changeable light source according to the present invention.

Fig. 4 is a view illustrating the structure of a third embodiment of a wavelength-changeable light source according to the present invention.

Figs. 5A, 5B, 5C, 5D, 5E, 5F and 5G are respectively representations for explaining the operation of a wavelength control conducted in the third embodiment.

Fig. 6 is a block diagram illustrating the structure of a wavelength division multiplexing communication network according to the present invention.

Fig. 7 is a view illustrating the structure of a first conventional art wavelength-changeable light source.

Fig. 8 is a view illustrating the structure of a second conventional art wavelength-changeable light source.

Fig. 9A is a graph showing the temperature-to-wavelength characteristic of a single-electrode DFB-LD.

Fig. 9B is a graph showing the current-to-wavelength characteristic of a single-electrode DFB-LD.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[First Embodiment]

A first embodiment of the present invention will be described with reference to Figs. 1 and 2.

Fig. 1 is a timing chart of the wavelength control performed by a wavelength-changeable light source of the present invention. In Fig. 1, the abscissa indicates time and the ordinate indicates the amount of a shift in the lasing wavelength. An uppermost part of Fig. 1 shows the wavelength shift by a current, its middle part shows the wavelength shift by temperature and its lowermost part shows the wavelength shift by the current plus temperature (i.e., a sum of the wavelength shift by the current and the wavelength shift by the temperature). The wavelength control for the wavelength shift will be referred to as a wavelength shift control hereinafter. In an example of Fig. 1, three wavelength shift controls indicated by #1, #2 and #3 are carried out. T11 indicates time at which the wavelength shift control #1 is started, T12 indicates time at which the wavelength shift by the wavelength shift control #1 is finished and T13

indicates time at which the control of the wavelength shift control #1 is finished. Likewise, T21, T22 and T23 respectively indicate times relevant to the wavelength shift control #2, and T31, T32 and T33 respectively indicate times relevant to the wavelength shift control #3. $\lambda S1$ indicates the amount of a wavelength shift attained in the wavelength shift control #1. Similarly, $\lambda S2$ and $\lambda S3$ respectively indicate the amounts of wavelength shifts attained in the wavelength shift controls #2 and #3. $\lambda Imax$ indicates a maximum value of a range of the wavelength shift which can be obtained by th control of a current.

Fig. 2 illustrates the structure of the first embodiment of a wavelength-changeable light source of the present invention. This light source is comprised of a single-electrode DFB-LD module 201, a current source 202, a temperature controller 203 and a wavelength control system #1 (204).

In the DFB-LD module 201, the above-discussed single-electrode DFB-LD is packaged together with an optical coupling system, an optical isolator, an optical fiber, a Peltier element, thermistor and so forth. Since the lasing wavelength of the single-electrode DFB-LD shifts due to a change in the ambient temperature, the device temperature of the single-electrode DFB-LD is controlled by the Peltier element and the thermistor. The optical isolator intercepts the return of light to the single-electrode DFB-LD and thus stabilizes the lasing wavelength of the single-electrode DFB-LD.

Further, the other structure of this embodiment is approximately the same as the structure of the conventional art device illustrated in Fig. 8. However, this embodiment is different therefrom in that the wavelength control system #1 (204) controls the output current of the current source 201. The wavelength control system #1 (204) is provided with a CPU, a memory and so forth, and controls the lasing wavelength of the DFB-LD module 201 by outputting the current control signal and the temperature control signal. Further, in the memory of the wavelength control system #1 (204), amounts of changes in the temperature control signal and the current control signal required for a given wavelength shift, operation procedures and timings for performing the wavelength control operation of this embodiment and the like are stored. It is assumed herein that the wavelength of the DFB-LD module 201 shifts toward a longer wavelength side as the current increases and as the temperature rises.

In this embodiment, the wavelength control operation in the wavelength shift control is divided into two stages. Initially, the current control signal is supplied from the wavelength control system #1 (204) to the current source 202, and the wavelength of the single-electrode DFB-LD module 201 is shifted on the basis of the current control signal (this period will be referred to as a first period hereinafter). Then, the temperature controller 203 supplies the Peltier drive current to the Peltier element in the single-electrode DFB-LD module 201 on the basis of the temperature control signal from the wavelength control system #1 (204) to shift the lasing wavelength of the DFB-LD, and this wavelength shift gradually replaces the amount of the wavelength shift caused by the precedent current control signal (this period will be referred to as a second period hereinafter).

Here, the length of the first period is determined by the amount of the wavelength shift and time required for the wavelength control system #1 (204) to control the current source 202, and the length of this period is approximately equal to 0.001 to 1 second. The length of the second period is determined by the amount of the wavelength shift and time required for the temperature controller 203 to control the temperature of the DFB-LD module 201 to a set temperature. This length ranges from the order of second to the order of minute. The amount of the current from the current source 202 reaches a predetermined value I0 on completion of each wavelength shift control. Here, the current I0 is an injection current at the time when the DFB-LD module 201 is in its oscillated state. In Fig. 1, the setting of a wavelength prior to and subsequent to the wavelength shift control is placed at a center of the wavelength-changeable range of the DFB-LD which can be attained by the current control.

In Fig. 1, the wavelength shift control for shifting the lasing wavelength of the DFB-LD to a longer wavelength side is performed three times. In the wavelength shift control #1, the wavelength shift control is started at time T11 and finished at time T13. The wavelength of the DFB-LD module 201 is shifted by $\lambda S1$ to a longer wavelength side by that wavelength shift control #1. During a period from time T11 to time T12, the wavelength control system #1 (204) increases the output current of the current source 202 and shifts the wavelength of the DFB-LD module 201 by $\lambda S1$ to a longer wavelength side. Then, during a period between time T12 and T13, the wavelength control system #1 (204) performs the current control of gradually decreasing the output current of the current source 202 and the temperature control of increasing the set temperature of the temperature controller 203, simultaneously. The control is conducted gradually. As a result, during the period between time T12 and time T13, the lasing wavelength of the DFB-LD module 201 is shifted $\lambda S1$ to a shorter wavelength side by the current control while shifted $\lambda S1$ to a longer wavelength side by the temperature control. Resultantly, the wavelength is maintained at $\lambda S1$ which is reached by the wavelength shift to a longer wavelength side during the period from time T11 to time T12. On completion of the wavelength shift control #1, the wavelength is shifted by $\lambda S1$ to a loner wavelength side, the temperature of the DFB-LD module 201 is increased and the current is returned to the value I0 prior to the control.

The same operation is executed in each of the wavelength shift control #2 and the wavelength shift control #3, and the wavelength are respectively shifted $\lambda S2$ and $\lambda S3$ to a longer wavelength side (here, the amount of the wavelength shift obtained in the wave-

length shift control #2 is equal to the maximum value λlmax of the wavelength shift to a longer wavelength side which can be attained by the current control). Time required for the wavelength shift control increases as the amount of the wavelength shift increases. Therefore, since λS2>λS1>λS3 in Fig. 1, the following relations exist:

$$(T22\text{-}T21) > (T12\text{-}T11) > (T32\text{-}T31) \text{ and}$$

$$(T23\text{-}T22) > (T13\text{-}T12) > (T33\text{-}T32)$$

After the wavelength shift control is performed three times, the wavelength of the DFB-LD module 201 is shifted to a longer wavelength side by the following amount:

$$\lambda S1 + \lambda S2 + \lambda S3$$

The lasing wavelength of the DFB-LD module 201 can be changed over a wide wavelength-changeable range, which can be obtained by the temperature control, by repeating the wavelength shift control. Further, the wavelength shift can also be performed in a short time in a narrow wavelength-changeable range which can be attained by the current control. Namely, the wavelength control system #1 (204) shifts the lasing wavelength of the DFB-LD in a short time by supplying to the current source 202 the current control signal corresponding to a desired amount of the wavelength shift, then increases the temperature control signal while gradually decreasing the current control signal with the lasing wavelength being maintained, and thus maintains the wavelength shift. This operation is the same in each of the wavelength shift controls #1 to #3.

In the foregoing, there is described the example for shifting the lasing wavelength to a longer wavelength side, but the operation is also the same where the wavelength is to be shifted to a shorter wavelength side. Further, the operation is the same even when the wavelength is to be alternately shifted to a shorter wavelength side and to a longer wavelength side. For example, when an instruction for shifting the wavelength by λS4 to a shorter wavelength side is given subsequent to the wavelength shift control #1, the wavelength control system #1 (204) shifts the wavelength to λS1 to λS4 in a short time by supplying the current control signal, which causes a decrease of the current to a given current, to the current source 202, and then decreases the temperature control signal while gradually increasing the current control signal such that the lasing wavelength is maintained at the value of λS1 to λS4. Also in this case, the value of the current from the current source 202 to the DFB-LD caused by the current control signal at the time of the oscillation at the wavelength value of λS1 to λS4 is equal to an original value of the current from the current source 202 at the time of the oscillation at an original wavelength, and the Peltier drive current has the amount of a current corresponding to the wavelength value of λS1 to λS4.

Furthermore, in the above embodiment, though an example of the wavelength shift in a short time is described using a low-cost single-electrode DFB-LD module, any ordinary semiconductor laser (LD) can also be used by constructing and operating this ordinary LD similarly to the above embodiment, if the lasing wavelength of this ordinary LD can be changed by the application of a current and the setting of temperature.

[Second Embodiment]

A second embodiment of the present invention will be described with reference to Fig. 3.

Fig. 3 illustrates the structure of a wavelength-changeable light source of the second embodiment. The second embodiment is comprised of a single-electrode DFB-LD module 201, a current source 202, a temperature controller 203, a wavelength control system #2 (301), a proportional amplifier 302, an integral amplifier #1 (303), an integral amplifier #2 (304), a subtracter 305, a reference voltage source 306 and an adder 307.

The DFB-LD module 201, the current source 202 and the temperature controller 203 are the same as those of the first embodiment illustrated in Fig. 2. The wavelength control system #2 (301) is approximately the same as the wavelength control system #1 (204) in Fig. 2. While the wavelength control system #1 (204) directly controls the current source 202 and the temperature controller 203, the wavelength control system #2 (301) indirectly controls the current source 202 and the temperature controller 203 through an analog arithmetic circuit.

The proportional amplifier 302, the integral amplifier #1 (303), the integral amplifier #2 (304), the subtracter 305, the reference voltage source 306 and the adder 307 constitute the analog arithmetic device of the second embodiment, which is a key portion. The proportional amplifier 302 is an amplifier whose band is from DC to the order of MHz. The amplification factor of the proportional amplifier 302, into which the wavelength control signal is input, is set such that the wavelength control system #2 (301) can control the wavelength of the DFB-LD module 201 to a predetermined value. The integral amplifier #1 (303) is an amplifier which is designed such that its integration time is in the order of 0.1 to 1 second, the wavelength control signal is input thereinto and its output comes to have the same value as that of the output of the proportional amplifier 302 after the integration time has passed. The integral amplifier #2 (304) is an integrator whose integration time is the same as that of the integral amplifier #1 (303). Its amplification factor is designed such that the wavelength control system #2 (301) can control the wavelength of the DFB-LD module 201 to a predetermined value. The wavelength control signal is input into the integral amplifier #2 (304) and the integral amplifier #2 (304) outputs the temperature control signal to the temperature controller 203. Further, the subtracter 305

subtracts a voltage at its negative (-) input terminal from a voltage at its positive (+) input terminal and outputs its result. The output of the proportional amplifier 302 is input into the positive input terminal of the subtracter 305 and the output of the integral amplifier #1 (303) is input into the negative input terminal of the subtracter 305. The reference voltage source 306 functions to maintain the output current of the current source 202 above a predetermined current I0. The adder 307 adds the outputs of the reference voltage source 306 and the subtracter 305, i.e, voltages at its two input terminals, and outputs its result to the current source 202 as the current control signal.

In the second embodiment, the controls of the current source 202 and temperature controller 203 during the wavelength shift control are not directly performed by the wavelength control system while the timing is measured, but are performed by the current control signal and the temperature control signal which are generated from the wavelength control signal from the wavelength control system #2 (301) by the analog operation in the electric circuit.

The wavelength control system #2 (301) performs the wavelength shift control by increasing (or decreasing) the wavelength control signal and then maintaining its value at a constant value. A case where the wavelength control signal is increased and the wavelength is shifted to a longer wavelength side will be described.

When the wavelength control signal is increased, the output of the proportional amplifier 302 increases, then the current control signal increases and the wavelength of the DFB-LD module 201 shifts to a longer wavelength side. Concurrently therewith, the outputs of the integral amplifier #1 (303) and the integral amplifier #2 (304) gradually increase, the current control signal gradually decreases and the temperature control signal gradually increases. As a result, the previous shift of the wavelength to a longer wavelength side by the current control is gradually replaced with the wavelength shift by the temperature control. After the integration times of the integral amplifier #1 (303) and the integral amplifier #2 (304) have passed, the current control signal comes to the output voltage of the reference voltage source 306 and the output current of the current source 202 is maintained at I0. On the other hand, the temperature control signal is increased by the amount corresponding to the wavelength shift.

Since the wavelength shift control equivalent to the operation example in Fig. 1 is executed by the analog operation in the second embodiment, a simpler wavelength control system can be used. Further, in the second embodiment, there is described the example wherein the wavelength control system #2 (301) does not monitor the temperature control monitor signal, which is different from the first embodiment, but the temperature control may be more accurately performed by conducting monitoring and feedback operation. Either temperature control may be adopted.

[Third Embodiment]

A third embodiment of the present invention will be described with reference to Fig. 4.

In the third embodiment, the wavelength-changeable light source and the method of controlling the wavelength changing established according to the present invention are applied to a wavelength control system used in a wavelength division multiplexing communication network.

Fig. 4 illustrates the structure of the third embodiment of a wavelength-changeable light source. There are arranged a single-electrode DFB-LD module 201, a current source 202, a temperature controller 203, a wavelength control system #2 (401) and a wavelength-placement detecting system 402. The structure other than the wavelength control system #3 (401) and the wavelength-placement detecting system 402 is the same as that of the first embodiment illustrated in Fig. 2.

The wavelength control system #3 (401) adjusts the current control signal and the temperature control signal on the basis of the wavelength-placement information and controls the wavelength of the DFB-LD module 201. The construction of the third embodiment is the same as that of the first embodiment with the exception that an input terminal for the wavelength-placement information is provided and the lasing wavelength of the DFB-LD module 201 is controlled on the basis of the wavelength-placement information.

The wavelength-placement detecting system 402 detects the wavelength placement on a transmission line in the wavelength division multiplexing communication network, and inputs the wavelength-placement information into the wavelength control system #3 (401). The wavelength-placement detecting system 402 can be comprised of an optical filter, such as a fiber Fabry-Perot filter, whose transmission wavelength can be controlled by a voltage control thereto, a control system therefor and an optical detecting system, for example. The wavelength-placement detecting system 402 sweeps its transmission wavelength when the control voltage applied thereto is swept by the wavelength control system #3 (401), and detects the wavelength placement from the placement in time of a train of pulses of electric signals (corresponding to the placement in wavelength of the lasing wavelengths on the transmission line) supplied from the optical detecting system.

Figs. 5A, 5B, 5C, 5D, 5E, 5F and 5G respectively illustrate the operations of the wavelength control of the third embodiment. Its abscissa indicates the wavelength and positions of vertical lines extending along its ordinate indicate the placement of the wavelengths. A series of seven states are shown and the manners of control are illustrated in Figs. 5A, 5B, 5C, 5D, 5E, 5F and 5G. In each operation, the wavelength control by the current (the current control) and the wavelength control by the temperature (the temperature control) are illustrated. In Figs. 5A, 5B, 5C, 5D, 5E, 5F and 5G, λO is a wavelength of the wavelength-changeable light

source in an optical node which is an object node to be described later, λA1, λA2 and λB are respectively wavelengths of wavelength-changeable light sources in other optical nodes which will also be described later and Δλ is a channel interval between adjacent wavelengths in the wavelength division multiplexing communication network.

Fig. 6 illustrates the structure of the wavelength division multiplexing communication network. In Fig. 6, optical nodes 601, 602 and 603, terminal stations 611, 612 and 613, a star coupler 620 and optical fibers 631, 632, 633, 641, 642 and 643 constitute the communication network. Each optical node includes an optical transmitter 651, an optical receiver and a power divider 653. The optical transmitter 651 includes the wavelength-changeable light source illustrated in Fig. 4. For simplicity of illustration, only three nodes are shown in Fig. 6, but more terminal stations and optical nodes may be arranged in the network of Fig. 6.

The terminal station 611 performs communication with another terminal station through the optical node 601. An optical signal from the optical transmitter 651 in the optical node 601 is sent to the star coupler 620 through the optical fiber 631, is power-divided into portions transmitted through the optical fibers 641, 642 and 643 and reaches the optical nodes including its own optical node 601. The optical signal from the optical transmitter 651 is output into the optical fiber 631, and the optical signal from the optical fiber 641 is power-divided at the power divider 653 and input into the optical transmitter 651 and the optical receiver 652. This is the same with regard to other terminal stations and optical nodes.

λ1, λ2 and λ3 are wavelengths of wavelength-changeable light sources in the optical transmitters 651 of the optical nodes 601, 602 and 603, respectively.

In the wavelength division multiplexing communication network, only the optical node, which performs communication, emits light and uses the wavelength range of wavelength multiplexing. To use this wavelength range effectively, the wavelength control system #3 (401) of the wavelength-changeable light source in each optical node detects the wavelength interval between its own wavelength and an adjacent wavelength thereto by using the wavelength-placement detecting system 402, and maintains this wavelength interval at Δλ. When the wavelength interval is measured from the adjacent wavelength on a longer wavelength side, lasing wavelengths are placed or arranged at the interval of Δλ from a longer wavelength side in the order of emission-start times.

Communication by each terminal station and each optical node in the wavelength multiplexing communication network illustrated in Fig. 6, particularly an example of the control operations of each optical node and the lasing wavelength of the wavelength-changeable light source (shown in Fig. 4) in the optical transmitter of each node, will be described with reference to Figs. 5A, 5B, 5C, 5D, 5E, 5F and 5G.

Fig. 5A shows a steady state. It is assumed that when the wavelength-changeable light source in the optical node, which is the object node to be described, starts oscillation, there already exist ten wavelengths (including λA1, λA2 and λB) on the transmission line of the optical fibers 641 to 643 at the wavelength interval of Δλ from a longer wavelength side in the wavelength range. This wavelength-changeable optical transmitter emits light of an eleventh wavelength (this eleventh wavelength of this wavelength-changeable optical transmitter is denoted by λO), and maintains the wavelength interval between the eleventh wavelength and the adjacent wavelength λA1 at Δλ. The control for maintaining the wavelength interval during the steady state is performed only by the current control from the current source 202 to the DFB-LD module 201 since the amount of the wavelength shift is small during the steady state.

Fig. 5B illustrates a state in which the emission of the wavelength λA1 on a longer wavelength side of the wavelength λO is stopped and hence the wavelength of λO is being shifted to bring the wavelength interval between this wavelength and the wavelength λA2 into Δλ. This wavelength shift is performed during the first period of the wavelength shift control described in the first embodiment or the second embodiment. For example, the wavelength is shifted to a longer wavelength side by the current control, such as the current controls between times T11 and T12, between times T21 and T22 and so forth, and the temperature control is constantly unchanged.

Fig. 5C shows a quasi-steady state in which the second period of the wavelength shift control is started, such as the periods between times T12 and T13, between times T22 and T23 and so forth. The temperature is gradually raised and concurrently the current value is gradually returned to the original value I0. Since the wavelength interval between λO of its own terminal station and the wavelength λA2 of the adjacent terminal station is measured by the wavelength-placement detecting system 402, the wavelength control system #3 (401) can perform the control without knowing details of the lasing wavelength characteristics of the DFB-LD module 201 relative to the current and the temperature beforehand.

The replacement of the current control with the temperature control will be conducted as follows. The detection of the wavelength placement and the wavelength control (in this case, the replacement of the current control with the temperature control) are repeated until the current value reaches I0. In each wavelength control, the current is decreased by a minute amount Is and the set temperature is increased by a minute amount Ts. The amount of the wavelength shift of the DFB-LD module 201 relative to Is is about equal to the amount of the wavelength shift of the DFB-LD module 201 relative to Ts. When the wavelength-placement detecting system detects the fact that the wavelength interval from the adjacent wavelength becomes narrow,

no temperature control is performed and the current is decreased by Is by the current control during the next wavelength control. Conversely, when the wavelength interval from the adjacent wavelength becomes wide, no current control is executed and the set temperature is increased by Ts by the temperature control during the next wavelength control.

Fig. 5D again illustrates the steady state in which the lasing wavelength of the optical transmitter in each node is stably maintained, such as the periods between times T13 and T21, between times T23 and T31 and so forth in Fig. 1. The situation is the same as that of Fig. 5A except that the adjacent wavelength is λA2 and the lasing wavelength of its own terminal station is a tenth wavelength. In this state, the wavelength interval from the adjacent wavelength on a longer wavelength side is maintained at Δλ by the current control.

Fig. 5E shows a state in which the oscillation at λB on a longer wavelength side of λA2 is stopped and the wavelength λA2 is being shifted to a longer wavelength side. Hence, this is the state in which the wavelength of λO is also being shifted to a longer wavelength side such that the wavelength interval from λA2 is brought to Δλ. This wavelength shift is conducted during the first period in the wavelength shift control. Namely, the optical transmitters in the respective optical nodes, whose lasing wavelengths are respectively λO and λA2, shift their wavelengths to a longer wavelength side by the current control, and maintain the temperature control constantly.

Fig. 5F shows the quasi-steady state in which the optical transmitters in the respective nodes, whose lasing wavelengths are respectively λO and λA2, gradually increase their temperatures and concurrently gradually return their current values to the original value I0. The wavelength changing control operation of the optical transmitter in each optical node is the same as the steady state of Fig. 5C except that their wavelengths are respectively eighth and ninth wavelengths, and a minute wavelength control is maintained by the current control.

Fig. 5G illustrates the steady state in which the operation is performed by the current control such that the wavelength interval between the lasing wavelength of the optical transmitter in each node and its adjacent wavelength is maintained at the wavelength interval of Δλ, similarly to the cases illustrated in Figs. 5A and 5D.

Since the wavelength interval Δλ is approximately 0.04 nm and the ratio of a change in the wavelength relative to the current of the DFB-LD module is approximately 0.008 nm/mA, for example, the wavelength shifts in Figs. 5B and 5E can be achieved by the current which is sufficiently obtained by the current control. Therefore, time required for the wavelength shift can be shortened, and the period of a state having the wavelength interval longer than Δλ can be shortened. Further, the varied current is returned to the original value during the steady state, so that the apparatus can respond to a next wavelength shift promptly.

Further, the ratio of a change in the wavelength relative to the temperature of the DFB-LD module is about 0.08 nm/°C. Since the temperature can be certainly changed over a range of about 20°C, the wavelength-changeable range of about 1.6 nm can be obtained by the temperature control.

When the wavelength-changeable light source of the present invention is used in the above wavelength control system, the wavelength division multiplexing communication network with about 40 (forty) channels can be built without using a high-cost multi-electrode wavelength-changeable LD.

[Other Embodiments]

In the above embodiments, a single-electrode DFB-LD module is used as the LD of the wavelength-changeable light source, but it is possible to use other LDs whose temperature can be changed. For example, "Heaters On Passive Region Employed (HOPE) DBR-LD" (Japanese Academy of Electronics Information Communications, Autumnal Meeting, 1992, Lecture No. C-149) can be used. This LD is a DBR-LD having a heater electrode formed in its wavelength control region.

In the above description, explanation is made by stating that the current value I0 before and after the wavelength shift control is constant, but it is possible to change this I0 depending on the situation of the temperature control. For example, it is possible to perform a control method in which the current value I0 is increased as the temperature increases in order to maintain the light output of the DFB-LD module at a constant intensity.

In the above description, the DFB-LD module has characteristics that the wavelength shifts to a longer wavelength side as the current increases and as the temperature rises, but the present invention can be practiced by using the LD with another characteristic.

In the first embodiment, explanation is made by stating that the lasing wavelength before and after the wavelength shift control is set at a center of the wavelength-changeable range which can be obtained by the current, but this lasing wavelength may be set at any place in the wavelength-changeable range. For example, where the wavelength-changeable light source of the present invention is used in a wavelength control system in which the wavelength is shifted exclusively to a longer wavelength side, the lasing wavelength before and after the wavelength shift control can be set at a shortest wavelength edge of the wavelength-changeable range attainable by the current control to widen a wavelength range over which the lasing wavelength can be speedily shifted.

In the first embodiment, the period (the first period) of the wavelength shift by the current control is clearly separated from the period (the second period) of the replacement of the current control by the temperature control, but it is possible to adopt a control system in which those periods are not clearly separated from

each other. Specifically, it is possible to adopt a control system in which the first period of a next wavelength shift control is started during the second period of a precedent wavelength shift control.

In the third embodiment, the lasing wavelengths of the wavelength division multiplexing communication network are placed from a longest wavelength edge to a shorter wavelength side of the wavelength range, but another method of the wavelength placement can be used. For example, the wavelengths can be placed from a shortest wavelength edge of the wavelength range.

Further, in the above embodiment, the first embodiment is used as the wavelength-changeable light source, but the wavelength-changeable light source of the second embodiment can be used similarly.

As described in the foregoing, according to the present invention, it is possible to provide a low-cost wavelength-changeable light source with a short response time and a wide wavelength-changeable range. Further, according to the control method of the wavelength-changeable light source, the wavelength shift control by the current control, in which the wavelength can be changed in a short time, is combined with the wavelength shift control executed by the temperature control to cancel the current control, and data communication can be performed among many terminal stations in a wavelength division multiplexing communication network system with a low-cost construction.

In a wavelength-changeable light source of the present invention, a wavelength control is performed using a plurality of control systems when the wavelength of a laser, particularly a semiconductor laser, is to be controlled. Wavelength control characteristics of the respective control systems are different from each other, and the wavelength control can be flexibly carried out by combining those characteristics. Specifically, one of the plural control systems is a current control unit for controlling a current supplied to the semiconductor laser and another thereof is a temperature control unit for controlling temperature of the semiconductor laser. In the structure, the wavelength shift with a speedy response time, which can be attained in a wavelength-changeable range obtainable by the current control, can be carried out over a wide wavelength-changeable range obtainable by the temperature control.

Claims

1. A wavelength-changeable light source comprising:

    a laser;
    first control means for continuously controlling a lasing wavelength of said laser with a short response time; and
    second control means for continuously controlling the lasing wavelength of said laser with a response time which is longer than the response time of the wavelength control executed by said first control means, wherein said second control means controls the lasing wavelength so as to change the lasing wavelength.

2. A wavelength-changeable light source according to claim 1, wherein said second control means performs such a control that the amount of a change in the lasing wavelength executed by said first control means is replaced by the amount of a change in the lasing wavelength executed by said second control means.

3. A wavelength-changeable light source according to claim 1, wherein said laser comprises a semiconductor laser.

4. A wavelength-changeable light source according to claim 3, wherein said first control means comprises current control means for controlling a current supplied to said semiconductor laser.

5. A wavelength-changeable light source according to claim 3, wherein said second means comprises temperature control means for controlling temperature of said semiconductor laser.

6. A wavelength-changeable light source according to claim 3, wherein said first control means comprises current control means for controlling a current supplied to said semiconductor laser, and said second means comprises temperature control means for controlling temperature of said semiconductor laser.

7. A wavelength-changeable light source according to claim 1, further comprising an analog arithmetic circuit for controlling said first control means and said second control means.

8. A wavelength-changeable light source according to claim 1, further comprising wavelength-placement detecting means for detecting placement of wavelengths on a transmission line to which output light of said laser is output, and wherein said first control means and said second control means perform controls on the basis of wavelength-placement information obtained from said wavelength-placement detecting means, respectively.

9. A wavelength-changeable light source comprising:

    a semiconductor laser;
    current control means for continuously controlling a lasing wavelength of said semiconductor laser by controlling a current supplied to said semiconductor laser; and
    temperature control means for continuously controlling the lasing wavelength of said semiconductor laser by controlling temperature of

said semiconductor laser, wherein said temperature control means controls the temperature so as to change the lasing wavelength.

10. A wavelength-changeable light source according to claim 9, wherein said temperature control means performs such a control that the amount of a change in the lasing wavelength executed by said current control means is replaced by the amount of a change in the lasing wavelength executed by said temperature control means.

11. A wavelength-changeable light source according to claim 9, further comprising an analog arithmetic circuit for controlling said current control means and said temperature control means.

12. A wavelength-changeable light source according to claim 9, further comprising wavelength-placement detecting means for detecting placement of wavelengths on a transmission line to which output light of said laser is output, and wherein said current control means and said temperature control means perform controls on the basis of wavelength-placement information obtained from said wavelength-placement detecting means, respectively.

13. A wavelength-changeable light source comprising:

a semiconductor laser;
current control means for continuously controlling a lasing wavelength of said semiconductor laser by controlling a current supplied to said semiconductor laser; and
temperature control means for continuously controlling the lasing wavelength of said semiconductor laser by controlling temperature of said semiconductor laser, said temperature control means performing such a control that the amount of a change in the lasing wavelength executed by the control of said current control means is replaced by the amount of a change in the lasing wavelength executed by the control of said temperature control means.

14. A wavelength-changeable light source according to claim 13, further comprising an analog arithmetic circuit for controlling said current control means and said temperature control means.

15. A wavelength-changeable light source according to claim 13, further comprising wavelength-placement detecting means for detecting placement of wavelengths on a transmission line to which output light of said laser is output, and wherein said current control means and said temperature control means perform controls on the basis of wavelength-placement information obtained from said wavelength-placement detecting means, respectively.

16. An optical communication network for performing communication by using light, said network comprising:

a transmission line for transmitting light therethrough; and
a wavelength-changeable light source for outputting light to said transmission line, said light source including:

a laser;
first control means for continuously controlling a lasing wavelength of said laser with a short response time; and
second control means for continuously controlling the lasing wavelength of said laser with a response time which is longer than the response time of the wavelength control executed by said first control means, wherein said second control means controls the lasing wavelength so as to change the lasing wavelength.

17. An optical communication network according to claim 16, wherein said wavelength-changeable light source further includes wavelength-placement detecting means for detecting placement of wavelengths on said transmission line, and wherein said first control means and said second control means perform controls on the basis of wavelength-placement information obtained from said wavelength-placement detecting means, respectively.

18. An optical communication network according to claim 17, wherein said first and second control means perform such a control that an interval between a wavelength adjacent to the wavelength of output light of said laser in the wavelength placement on said transmission line and the wavelength of the output light of said laser is maintained at a predetermined interval.

19. An optical communication network for performing communication by using light, said network comprising:

a transmission line for transmitting light therethrough; and
a wavelength-changeable light source for outputting light to said transmission line, said light source including:

a semiconductor laser;
current control means for continuously controlling a lasing wavelength of said semiconductor laser by controlling a current supplied to said semiconductor laser; and
temperature control means for continu-

ously controlling the lasing wavelength of said semiconductor laser by controlling temperature of said semiconductor laser, wherein said temperature control means controls the temperature so as to change the lasing wavelength.

20. An optical communication network according to claim 19, wherein said wavelength-changeable light source further includes wavelength-placement detecting means for detecting placement of wavelengths on said transmission line, and wherein said current control means and said temperature control means perform controls on the basis of wavelength-placement information obtained from said wavelength-placement detecting means, respectively.

21. An optical communication network according to claim 20, wherein said current control means and said temperature control means perform such a control that an interval between a wavelength adjacent to the wavelength of output light of said laser in the wavelength placement on said transmission line and the wavelength of the output light of said laser is maintained at a predetermined interval.

22. An optical communication network for performing communication by using light, said network comprising:

a transmission line for transmitting light therethrough; and
a wavelength-changeable light source for outputting light to said transmission line, said light source including:

a semiconductor laser;
current control means for continuously controlling a lasing wavelength of said semiconductor laser by controlling a current supplied to said semiconductor laser; and
temperature control means for continuously controlling the lasing wavelength of said semiconductor laser by controlling temperature of said semiconductor laser, said temperature control means performing such a control that the amount of a change in the lasing wavelength executed by the control of said current control means is replaced by the amount of a change in the lasing wavelength executed by the control of said temperature control means.

23. An optical communication network according to claim 22, wherein said wavelength-changeable light source further includes wavelength-placement detecting means for detecting placement of wavelengths on said transmission line, and wherein said current control means and said temperature control means perform controls on the basis of wavelength-placement information obtained from said wavelength-placement detecting means, respectively.

24. An optical communication network according to claim 23, wherein said current control means and said temperature control means perform such a control that an interval between a wavelength adjacent to the wavelength of output light of said laser in the wavelength placement on said transmission line and the wavelength of the output light of said laser is maintained at a predetermined interval.

25. A wavelength control method for controlling a wavelength of output light from a semiconductor laser, said method comprising the steps of:

controlling a current supplied to the semiconductor laser to continuously change the wavelength of the output light; and
continuously controlling temperature of the semiconductor laser to replace the amount of a change in the wavelength executed by the current control with the amount of a change in the wavelength executed by the temperature control.

26. A wavelength control method according to claim 25, wherein the change in the wavelength executed by the current control is a predetermined amount of a change in the wavelength.

FIG. 1

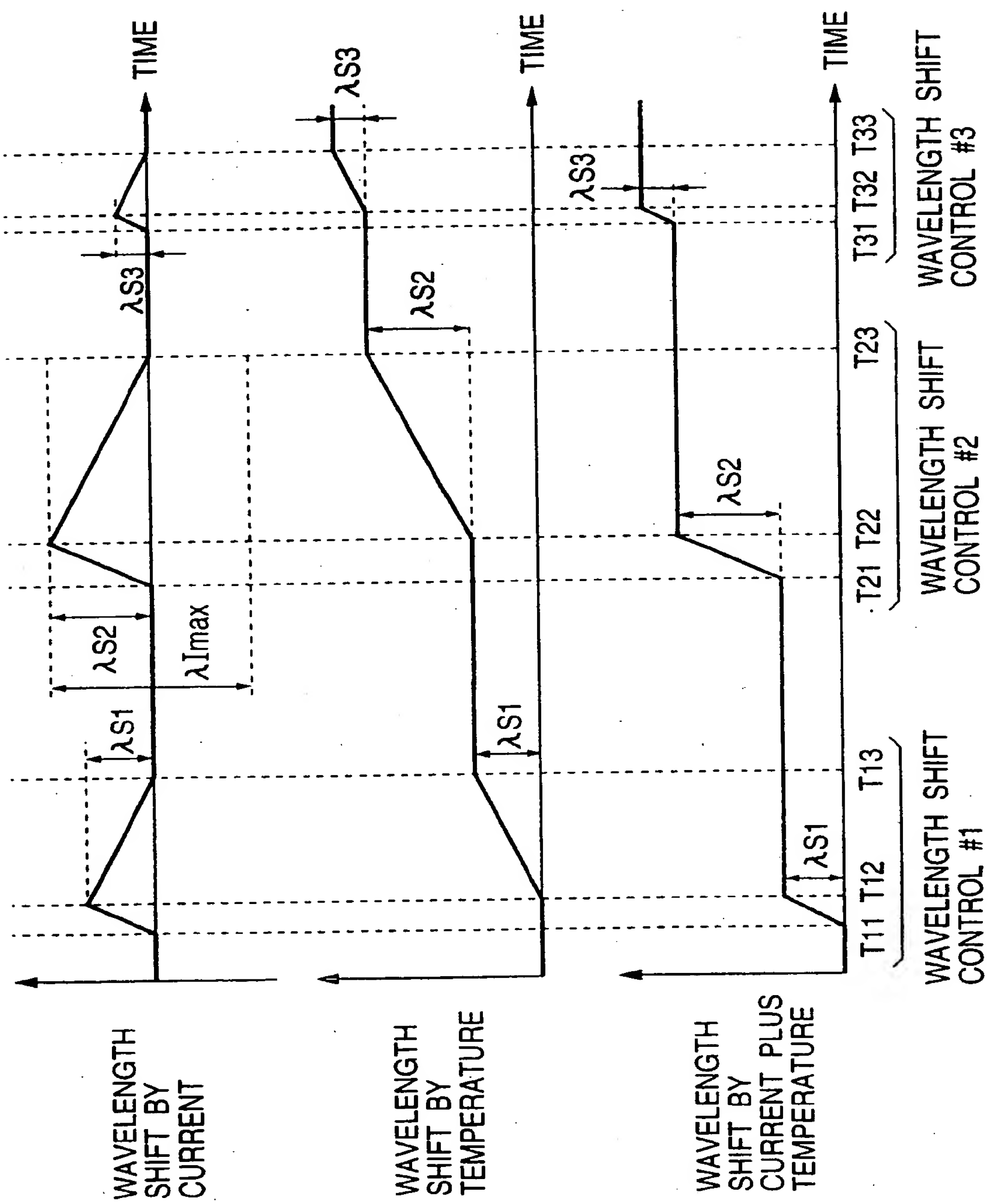

WAVELENGTH SHIFT BY CURRENT
WAVELENGTH SHIFT BY TEMPERATURE
WAVELENGTH SHIFT BY CURRENT PLUS TEMPERATURE
TIME
TIME
TIME
λS1
λS2
λImax
λS3
λS1
λS2
λS3
λS1
λS2
λS3
T11 T12
T13
T21 T22
T23
T31 T32 T33
WAVELENGTH SHIFT CONTROL #1
WAVELENGTH SHIFT CONTROL #2
WAVELENGTH SHIFT CONTROL #3

FIG. 2

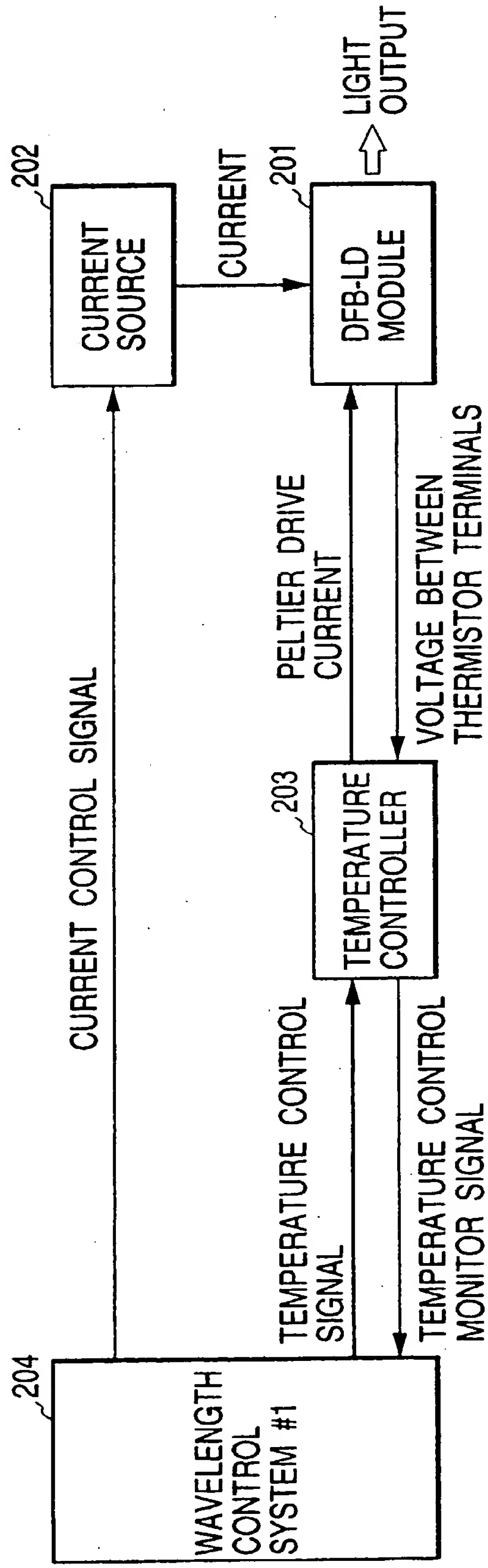

202
CURRENT SOURCE
CURRENT
201
DFB-LD MODULE
LIGHT OUTPUT
CURRENT CONTROL SIGNAL
PELTIER DRIVE CURRENT
VOLTAGE BETWEEN THERMISTOR TERMINALS
203
TEMPERATURE CONTROLLER
TEMPERATURE CONTROL SIGNAL
TEMPERATURE CONTROL MONITOR SIGNAL
204
WAVELENGTH CONTROL SYSTEM #1

FIG. 3

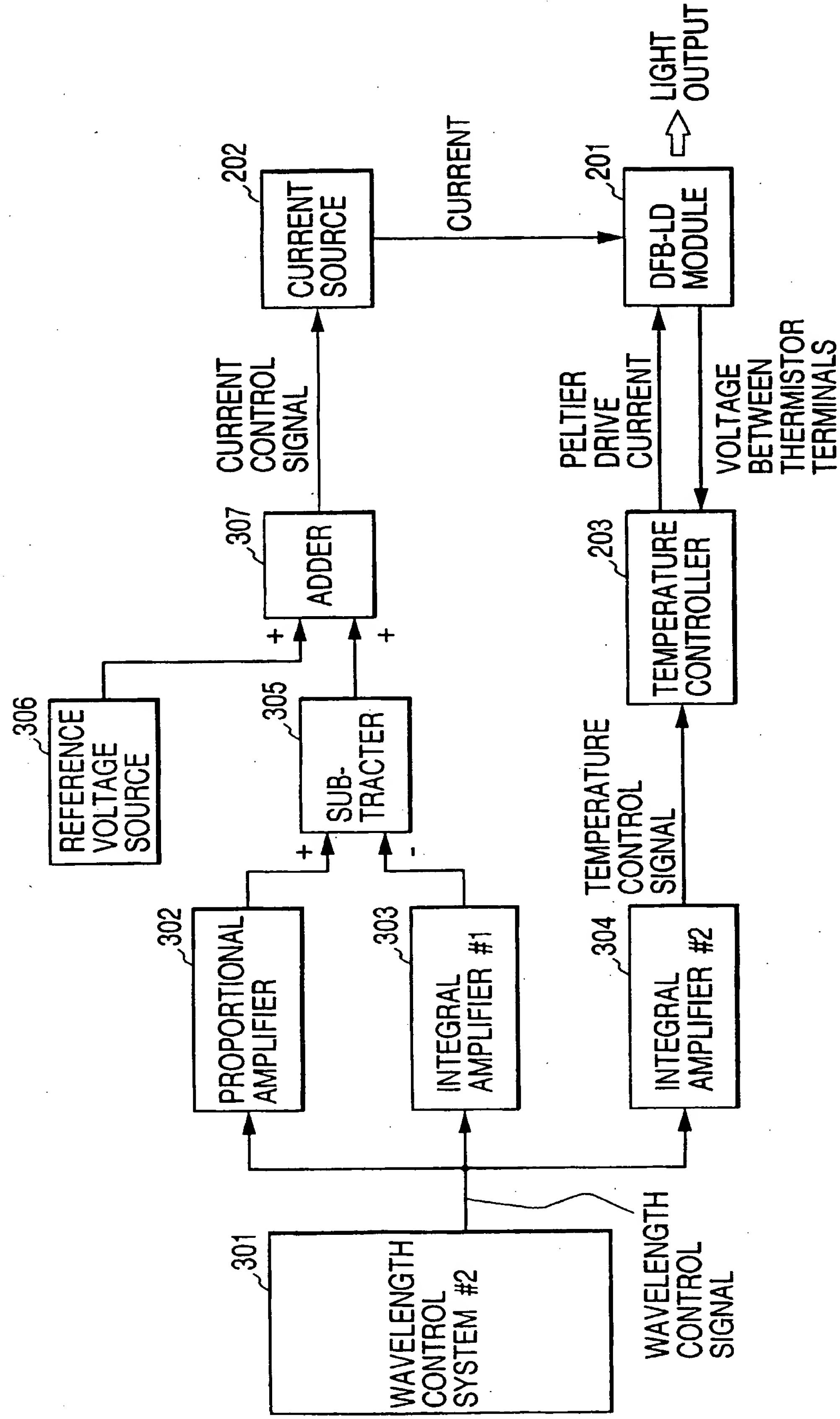
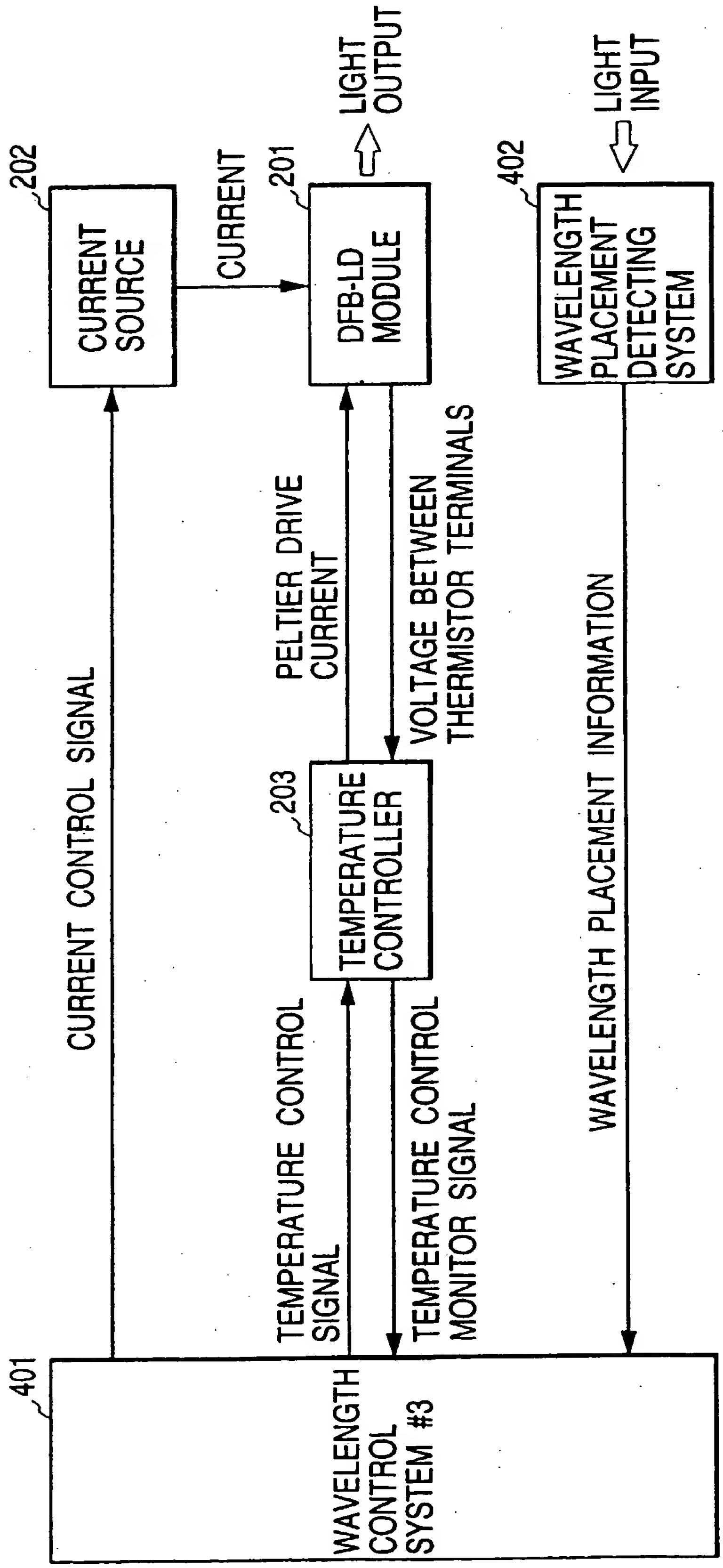
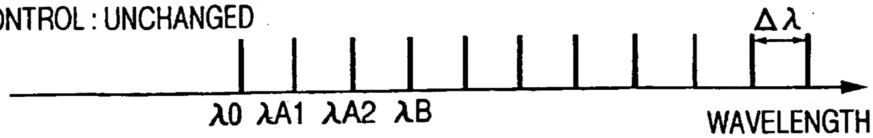

301
WAVELENGTH CONTROL SYSTEM #2
WAVELENGTH CONTROL SIGNAL
302
PROPORTIONAL AMPLIFIER
303
INTEGRAL AMPLIFIER #1
304
INTEGRAL AMPLIFIER #2
TEMPERATURE CONTROL SIGNAL
305
SUB-TRACTER
+
-
306
REFERENCE VOLTAGE SOURCE
307
ADDER
+
+
CURRENT CONTROL SIGNAL
202
CURRENT SOURCE
CURRENT
201
DFB-LD MODULE
LIGHT OUTPUT
203
TEMPERATURE CONTROLLER
PELTIER DRIVE CURRENT
VOLTAGE BETWEEN THERMISTOR TERMINALS

FIG. 4


202
CURRENT SOURCE
CURRENT
201
DFB-LD MODULE
LIGHT OUTPUT
402
WAVELENGTH PLACEMENT DETECTING SYSTEM
LIGHT INPUT
CURRENT CONTROL SIGNAL
PELTIER DRIVE CURRENT
VOLTAGE BETWEEN THERMISTOR TERMINALS
WAVELENGTH PLACEMENT INFORMATION
203
TEMPERATURE CONTROLLER
TEMPERATURE CONTROL SIGNAL
TEMPERATURE CONTROL MONITOR SIGNAL
401
WAVELENGTH CONTROL SYSTEM #3

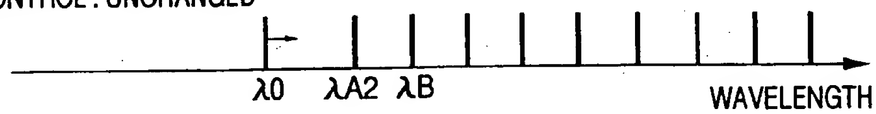
STEADY STATE
CURRENT CONTROL : INCREASE AND DECREASE ARE REPEATED
TEMPERATURE CONTROL : UNCHANGED

FIG. 5A



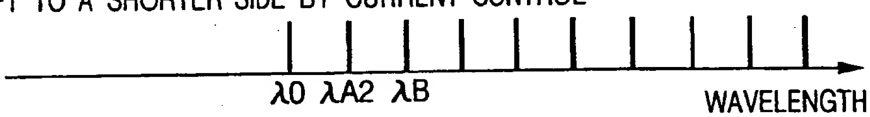
OSCILLATION OF ADJACENT WAVELENGTH λA1 IS STOPPED
CURRENT CONTROL : CURRENT INCREASES AND WAVELENGTH SHIFTS TO A LONGER SIDE
TEMPERATURE CONTROL : UNCHANGED

FIG. 5B



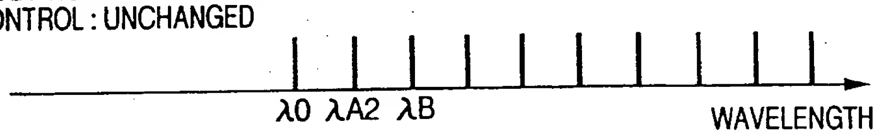
QUASI-STEADY STATE
CURRENT CONTROL : CURRENT VALUE GRADUALLY RETURNS TO ORIGINAL VALUE
TEMPERATURE CONTROL : TEMPERATURE GRADUALLY INCREASES TO CANCEL WAVELENGTH SHIFT TO A SHORTER SIDE BY CURRENT CONTROL

FIG. 5C



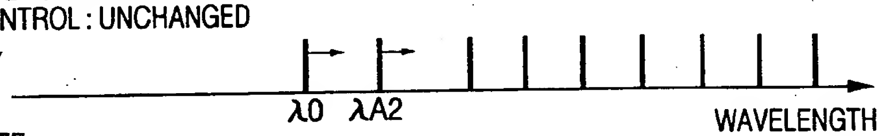
STEADY STATE
CURRENT CONTROL : INCREASE AND DECREASE ARE REPEATED
TEMPERATURE CONTROL : UNCHANGED

FIG. 5D



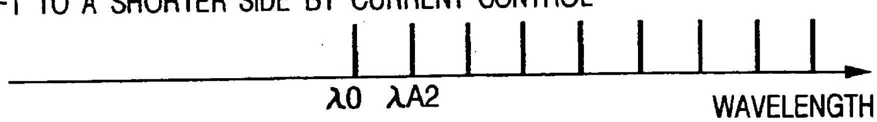
OSCILLATION OF λB IS STOPPED AND WAVELENGTHS ON A SHORTER WAVELENGTH SIDE THAN λB SHIFT TO A LONGER SIDE
CURRENT CONTROL : CURRENT INCREASES AND WAVELENGTH SHIFTS TO A LONGER SIDE
TEMPERATURE CONTROL : UNCHANGED

FIG. 5E



QUASI-STEADY STATE
CURRENT CONTROL : CURRENT VALUE GRADUALLY RETURNS TO ORIGINAL VALUE
TEMPERATURE CONTROL : TEMPERATURE GRADUALLY INCREASES TO CANCEL WAVELENGTH SHIFT TO A SHORTER SIDE BY CURRENT CONTROL

FIG. 5F



STEADY STATE
CURRENT CONTROL : INCREASE AND DECREASE ARE REPEATED
TEMPERATURE CONTROL : UNCHANGED

FIG. 5G

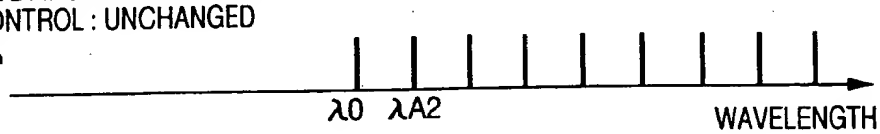


FIG. 6

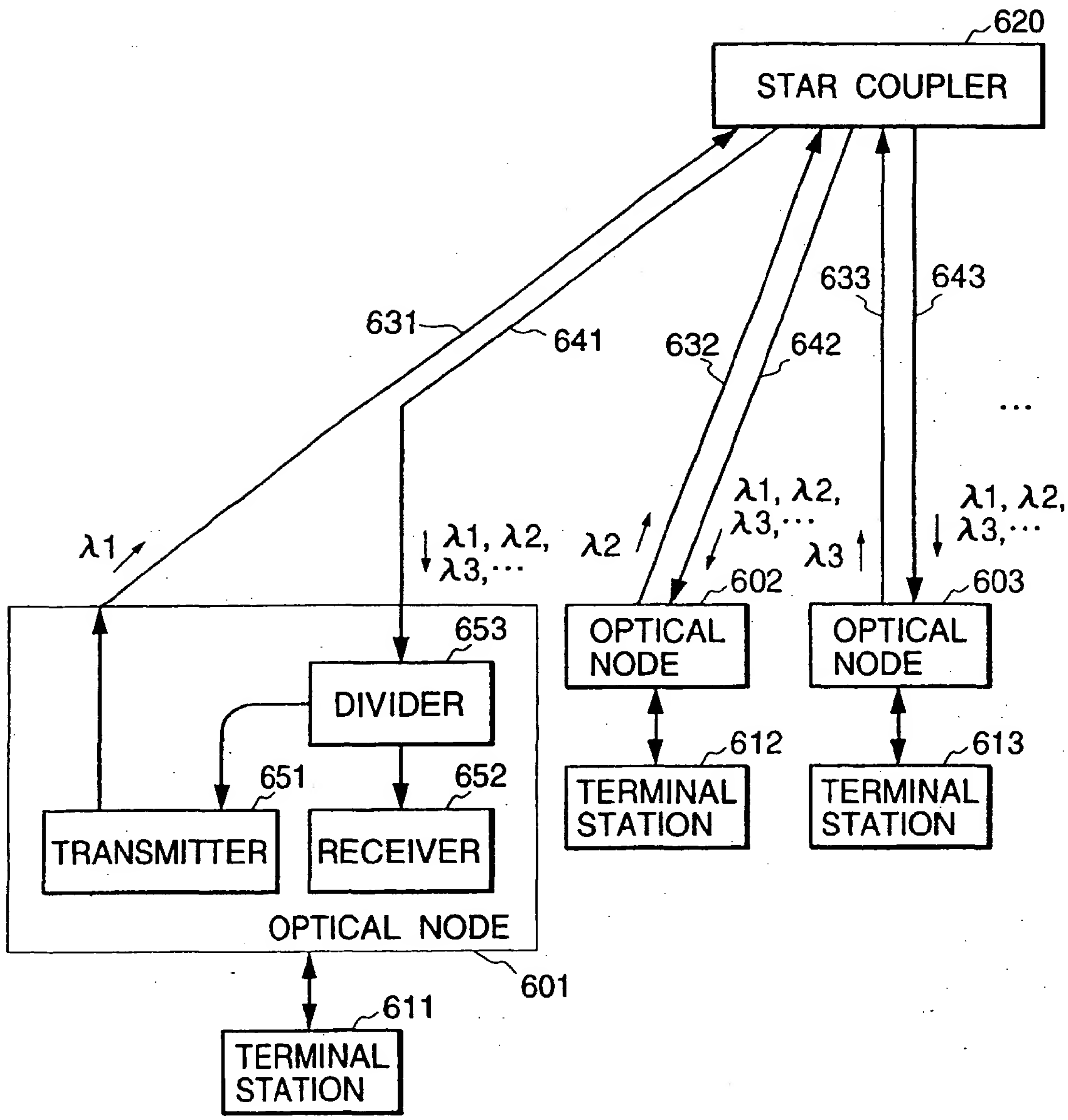

620
STAR COUPLER
631
641
632
642
633
643
λ1
λ1, λ2,
λ3,···
λ2
λ1, λ2,
λ3,···
λ3
λ1, λ2,
λ3,···
602
603
653
DIVIDER
651
652
TRANSMITTER
RECEIVER
OPTICAL NODE
601
611
TERMINAL
STATION
OPTICAL
NODE
612
TERMINAL
STATION
OPTICAL
NODE
613
TERMINAL
STATION
...

FIG. 7 CONVENTIONAL ART

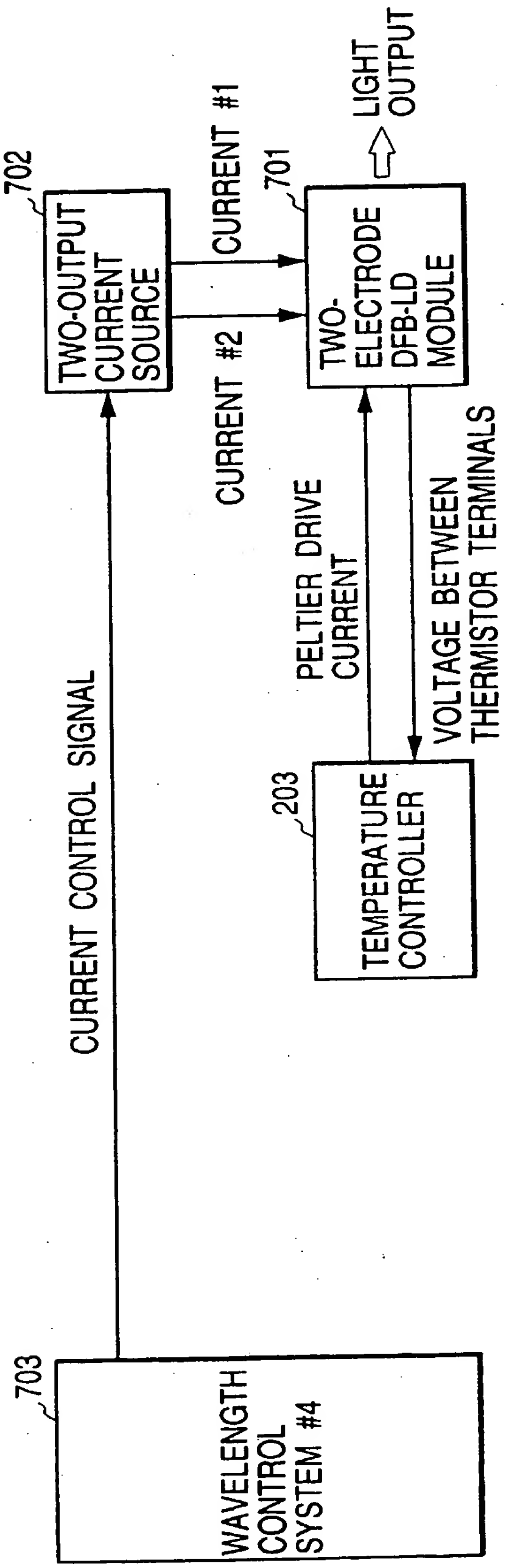


FIG. 8 CONVENTIONAL ART

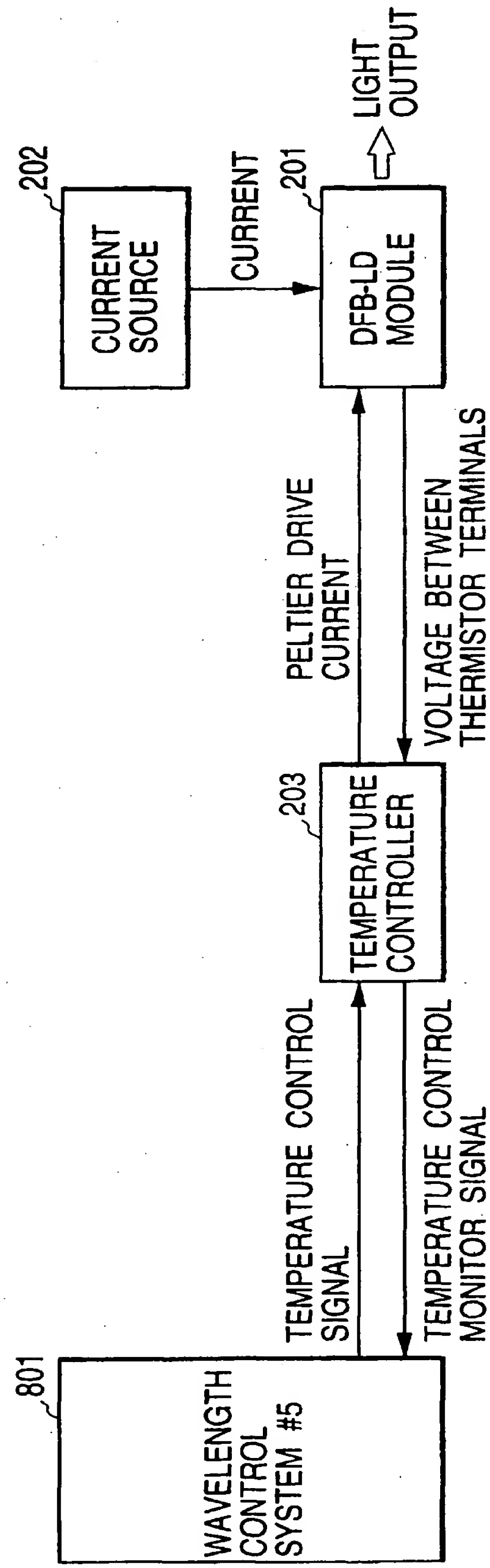


FIG. 9A

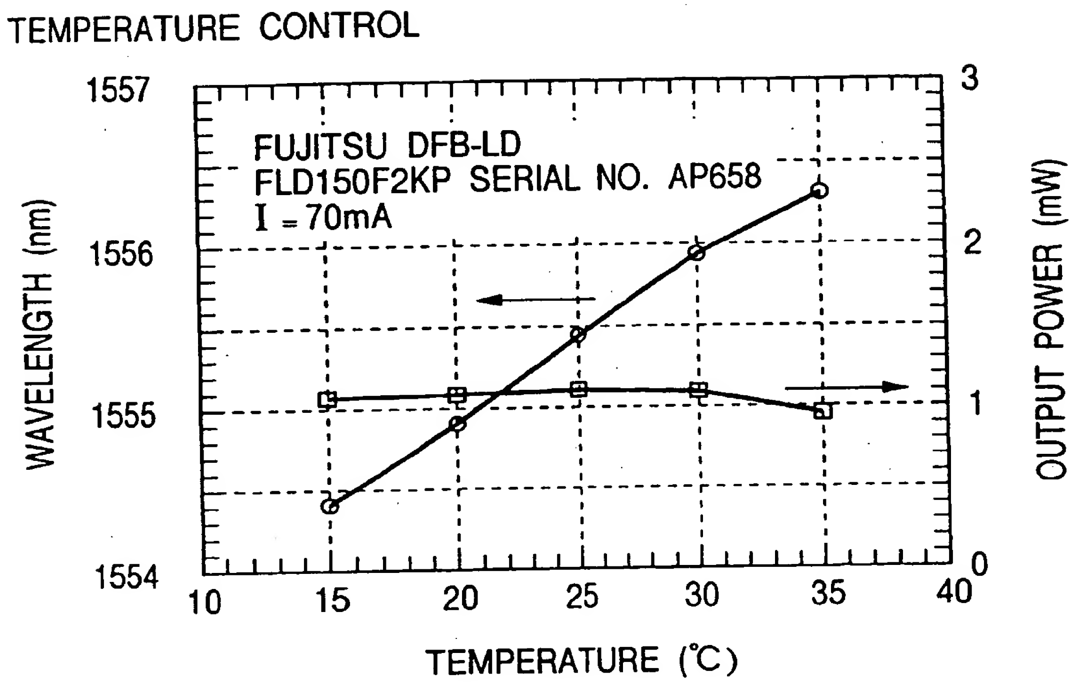
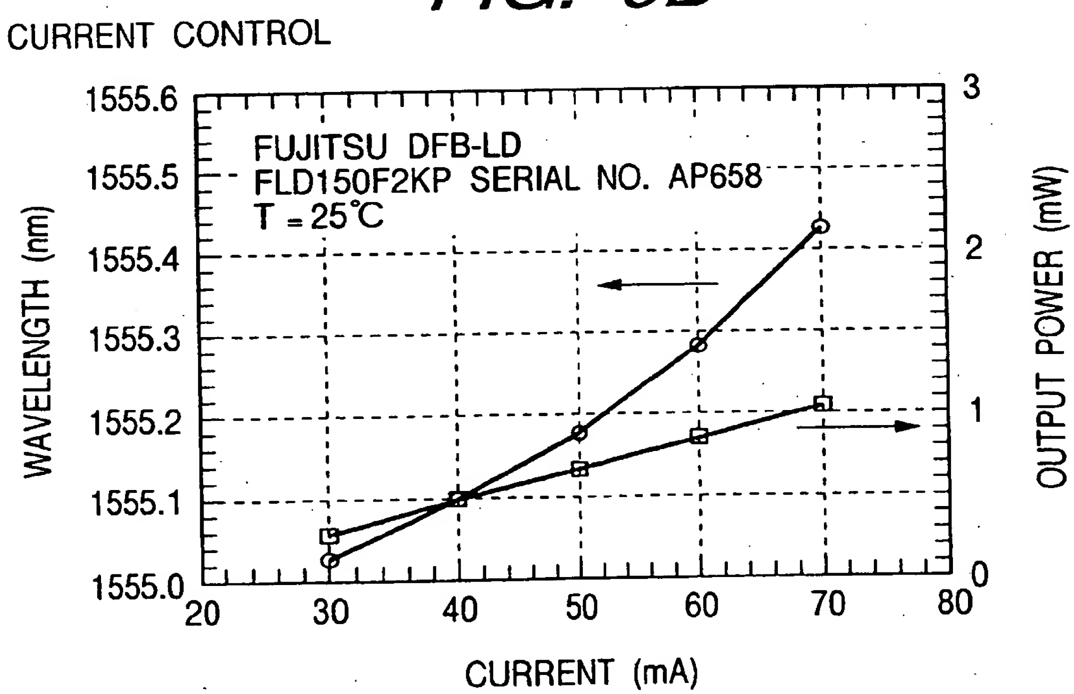

TEMPERATURE CONTROL
FUJITSU DFB-LD
FLD150F2KP SERIAL NO. AP658
I = 70mA
WAVELENGTH (nm)
1557
1556
1555
1554
OUTPUT POWER (mW)
3
2
1
0
10
15
20
25
30
35
40
TEMPERATURE (℃)

FIG. 9B


CURRENT CONTROL
FUJITSU DFB-LD
FLD150F2KP SERIAL NO. AP658
T = 25℃
WAVELENGTH (nm)
1555.6
1555.5
1555.4
1555.3
1555.2
1555.1
1555.0
OUTPUT POWER (mW)
3
2
1
0
20
30
40
50
60
70
80
CURRENT (mA)

(19) Europäisches Patentamt
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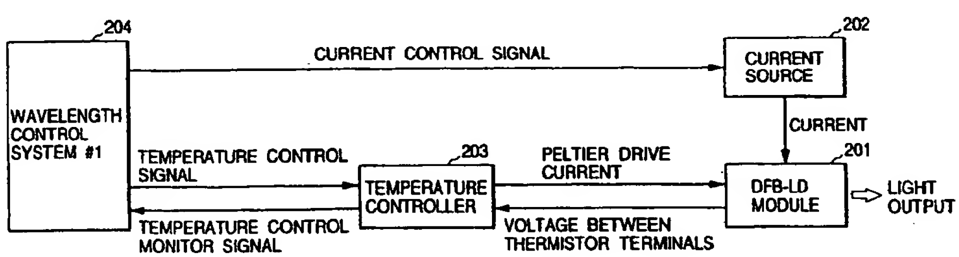
(54) Wavelength-changeable light source capable of changing wavelength of output light, optical communication network using the same and wavelength control method for controlling wavelength of output light of the same

(57) In a wavelength-changeable light source of the present invention, a wavelength control is performed using a plurality of control systems when the wavelength of a laser, particularly a semiconductor laser, is to be controlled. Wavelength control characteristics of the respective control systems are different from each other, and the wavelength control can be flexibly carried out by combining those characteristics. Specifically, one of the plural control systems is a current control unit for controlling a current supplied to the semiconductor laser and another thereof is a temperature control unit for controlling temperature of the semiconductor laser. In the structure, the wavelength shift with a speedy response time, which can be attained in a wavelength-changeable range obtainable by the current control, can be carried out over a wide wavelength-changeable range obtainable by the temperature control.

FIG. 2



EP 0 813 272 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 10 9410

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	WO 96 10855 A (SDL INC) 11 April 1996 * page 14, line 1 - page 16, line 2; figures 2-5 * ---	1,3-6,9, 13,16, 19,22,25	H01S3/103 H01S3/133 H04B10/14
A	US 4 897 843 A (SCOTT PETER B) 30 January 1990 * column 2, line 41 - column 4, line 45; figures 1-4 * ---	1,9,13, 15,19, 22,25	
A	JP 07 086694 A (TOSHIBA CORP) 31 March 1995	1,3-6,9, 13,16, 19,22,25	
P,A	-& US 5 642 371 A (MASAKI TOHYAMA ET AL.) 24 June 1997 * column 1, line 6 - column 1, line 10 * * column 2, line 38 - column 2, line 64 * * column 7, line 66 - column 8, line 40 * * column 11, line 19 - column 11, line 65 * * column 13, line 29 - column 14, line 28; claim 1; figures 1,7-9,15 * ---	1,3-6,9, 13,16, 19,22,25	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01S
A	EP 0 529 731 A (PHILIPS NV) 3 March 1993 * page 1, line 1 - page 1, line 9 * * page 4, line 36; figure 1 * ---	1,3-6,9, 13,16, 19,22,25	
A	US 4 792 956 A (KAMIN GEORGE W) 20 December 1988 * column 1, line 1 - column 1, line 16 * * column 1, line 66 - column 2, line 13; claim 1; figure 1 * --- -/--	1,3-6,9, 13,16, 19,22,25	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	15 April 1999	Gnugesser, H

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 10 9410

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	OBERG M ET AL: "A THREE-ELECTRODE DISTRIBUTED BRAGG REFLECTOR LASER WITH 22 NM WAVELENGTH TUNING RANGE" IEEE PHOTONICS TECHNOLOGY LETTERS, vol. 3, no. 4, 1 April 1991, pages 299-301, XP000227561 * the whole document * -----	1,3-6,9, 13,16, 19,22,25	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	15 April 1999	Gnugesser, H

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 97 10 9410

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15-04-1999

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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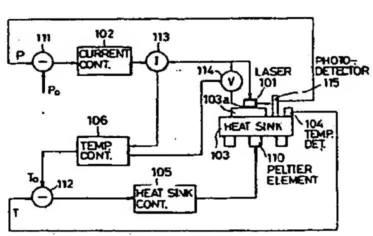
(54) **Frequency stabilization method of semiconductor laser, frequency-stabilized light source and laser module.**

(57) A frequency stabilization method of a semiconductor laser is provided. A driving current, a forward voltage and an output light power of the laser mounted on a heat sink is detected. A temperature of the heat sink is also detected. A consumption power of the laser is obtained from the driving current and voltage thus detected, providing a relationship between the output light power and the consumption power. The driving current is controlled so that the output light power is kept constant, and the temperature of the heat sink is controlled based on the relationship so that a temperature of an active layer of the laser is maintained. The output light power is kept constant and at the same time, any temperature change of the active layer is cancelled through the temperature control of the heat sink. Even if the consumption power changes due to an leakage current and/or a recombination current without luminescence to maintain the output light power during long time operation, the temperature of the active layer is maintained by cancelling the consumption power change through the temperature control of the heat sink. Thus, the oscillation frequency of the semiconductor laser can be stabilized at a given value.

FIG. 3



EP 0 618 653 A2

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a semiconductor laser and more particularly, to a frequency stabilization method of a semiconductor laser, a frequency-stabilized light source and a semiconductor laser module used for the method.

2. Description of the prior art

A conventional frequency stabilization method of a semiconductor laser is disclosed in the IEEE Journal of Quantum Electronics, Vol. 28, No. 1, Page 75, January 1992, in which an oscillation frequency of the laser is stabilized at an absorption line frequency of acetylene. Fig. 1 shows a functional block diagram of the conventional frequency stabilization method.

In Fig. 1, the ambient temperature of a semiconductor laser 701 is kept constant by a temperature controller 702. A DC power supply 709 supplies a driving current to the laser 701. The driving current is slightly modulated in frequency by a modulation signal outputted from an oscillator 703, resulting in frequency-modulated output light beams of the laser 701.

One of the output light beams of the laser 701 is emitted from a side face of the laser 701 and used for a given application. The other of the output light beams of the laser 701 is emitted from its opposite side face and goes through an optical lens system 708 to be injected into an acetylene (C_2H_2) gas cell 704. The light beam transmitted through the acetylene gas cell 704 is detected by a photodetector 705 to produce an electrical output signal. The electrical output signal is inputted into an lock-in amplifier 706 to be detected synchronously with the modulation frequency from the oscillator 703.

The lock-in amplifier 706 produces an electrical output signal proportional to a difference or error between the oscillation frequency of the laser 701 and one of absorption peak frequencies of acetylene in the cell 704. The electrical output signal from the amplifier 706 is fed-back to the driving current through a PID controller 707 in which a Proportional, Integral and Differential (PID) controlling method is employed. Thus, the laser 701 is controlled so that its, oscillation frequency is kept to be in accordance with the absorption peak frequency of acetylene.

Due to high stability in the absorption peak frequency, the oscillation frequency of the semiconductor laser 701 can be highly stabilized or locked.

With the conventional frequency stabilization method shown in Fig. 1, to obtain the difference or error between the oscillation frequency and the absorption peak frequency, the gas cell 704 and the lock-in amplifier 706 are required, and the driving current is modulated in frequency to be injected into the laser 701. As a result, there arises disadvantages that large-sized and expensive setups or apparatuses are necessary for carrying out the method and no unmodulated output light beam can be obtained.

In the case of stabilizing the optical output power of the laser 701 during operation, there is another disadvantage that another photodetector is necessary in addition to the photodetector 705.

Further, there is still another disadvantage that stabilizable oscillation frequencies are restricted to the absorption peak frequencies of the gas in the cell 704, so that any or arbitrary oscillation frequencies cannot be selected.

Another conventional frequency stabilization method of a semiconductor laser is disclosed in the Japanese Non-Examined Patent Publication No. 64-74780, March 1989, in which a semiconductor laser temperature is detected from a forward voltage of the laser to keep the temperature constant. Fig. 2 shows a functional block diagram of the conventional frequency stabilization method.

In Fig. 2, a semiconductor laser 803 and a Peltier element 802 which generates and absorbs heat are arranged in a thermostatic bath 801. The laser 803 is driven by a constant current supplied from a DC current source 804. A differential amplifier 805 detects between input terminals or electrodes of the laser 803 its forward voltage drop V_f, and sends an electrical output signal proportional the voltage drop V_f to a temperature controller 806.

In response to the output signal from the amplifier 805, the controller 806 increases or decreases a driving current for the Peltier element 801 to thereby keep the temperature of the laser 803 constant.

In general, the forward voltage drop V_f of the semiconductor laser 803 is expressed as

$$V_f = \frac{k \cdot I_p\left(1 + \frac{I_f}{I_0}\right)}{e \cdot T} \qquad (1)$$

where I_0 is the forward saturation current, I_f is a driving or exciting current, T is the absolute temperature of the laser 803, e is the charge of an electron and k is the Boltzmann's constant.

To be seen from the equation (1), the forward voltage drop V_f is inversely proportional to the absolute temperature T. Thus, the absolute temperature T of the laser 803 can be exactly measured from the voltage drop V_f.

The differential amplifier 805 produces an output signal relating to the absolute temperature T from the detected voltage drop V_f and sends the signal to the temperature controller 806. In response to the signal, the controller 806 controls to keep the temperature of the laser 803 constant.

The oscillation frequency of the semiconductor laser 803 is decided by the absolute temperature T and driving current I_f, so that it can be seen that the oscillation frequency is stabilized if both of them are kept constant.

With the another conventional frequency stabilization method shown in Fig. 2, an error tends to arise in detection of the absolute temperature T through the differential amplifier 805 because the laser 803 has an leakage current and a recombination current without luminescence both of which increase with the passage of time, providing fluctuation or deviation in the absolute temperature T and driving current I_f.

As a result, there arises a disadvantage that the output light power and oscillation frequency of the laser 803 deviate from the given values, respectively.

In addition to the above methods, still another conventional frequency stabilization method of a semiconductor laser is disclosed in the Japanese Non-Examined Patent Publication No. 1-238083, September 1989. In the method, similar to the conventional method shown in Fig. 2, absorption peak frequencies of a gas is used.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a frequency stabilization method of a semiconductor laser and a frequency-stabilized light source in which only a simple, compact and low-cost setup is necessary.

A further object of the present invention is to provide a frequency stabilization method of a semiconductor laser and a frequency-stabilized light source in which an output light power and an oscillation frequency of the semiconductor laser can be maintained even if the laser operates for a long period of time.

Another object of the present invention is to provide a frequency stabilization method of a semiconductor laser and a frequency-stabilized light source in which unmodulated light output can be obtained.

Still another object of the present invention is to provide a frequency stabilization method of a semiconductor laser and a frequency-stabilized light source in which both of the oscillation frequency and the output light power of the laser can be stabilized.

Still another object of the present invention is to provide a frequency-stabilized semiconductor laser module which enables the semiconductor laser to operate stably.

According to a first aspect of the present invention, a frequency stabilization method of a semiconductor laser is provided, which includes the steps of detecting an output light power of a semiconductor laser mounted on the heat sink, obtaining a consumption power of the laser, obtaining a relationship between the output light power and the consumption power, detecting a temperature of the heat sink, controlling a driving current for the laser so that the output light power is kept constant, and controlling the temperature of the heat sink based on the relationship so that a temperature of an active layer of the laser is maintained.

With the frequency stabilization method of the semiconductor laser according to the first aspect, the output light power is kept constant and at the same time, any temperature change of the active layer is cancelled through the temperature control of the heat sink. Therefore, even if the consumption power changes due to an leakage current and/or a recombination current without luminescence in order to maintain the output light power during long time operation, the temperature of the active layer is maintained by cancelling the consumption power change through the temperature control of the heat sink.

As a result, the oscillation frequency of the semiconductor laser can be stabilized at a given value for a long time operation, which means no oscillation frequency drift. Additionally, the output light power also can be maintained.

Further, since no gas cell and no synchronous detection means are required, only a simple, compact and low-cost setup is sufficient for the method.

According to a second aspect of the present invention, a frequency-stabilized light source is provided, which enables the method of the first aspect to be carried out.

The light source includes a current detector for detecting a light power detector for detecting an output light power of a laser mounted on a heat sink, a light power detector for detecting an output light power of a semiconductor laser mounted on a heat sink, a first operator for obtaining a consumption power of the laser, a second operator for obtaining a relationship between the output light power and the consumption power, a temperature detector for detecting a temperature of the heat sink, a first controller for controlling the driving current so that the output light power is kept constant, and a second controller for controlling the temperature of the heat sink based on the relationship so that a temperature of an active layer of said laser is maintained.

With the frequency-stabilized light source according to the second aspect, the frequency stabilization method of the first aspect is carried out, so that the same effects or advantages as those in the first aspect can be obtained.

According to a third aspect of the present invention, a frequency stabilization method of a semiconductor laser is provided, which includes the steps of injecting an output light beam from a semiconductor laser into an optical resonator, modulating a temperature of the optical resonator by a modulation signal, detecting a transmitted light beam through the optical resonator to produce a first output signal, synchronously detecting the first output signal with the modulation frequency to produce a second output signal, controlling an oscillation frequency of the semiconductor laser to keep the frequency at a given value using the second output signal as a signal showing an error in the oscillation frequency.

With the frequency stabilization method of a semiconductor laser according to the third aspect, no gas cell is required, so that only a simple, compact and low-cost setup is sufficient for the method.

Since the output light beam from the semiconductor laser itself is not modulated and the temperature of the optical resonator is modulated, an unmodulated output light beam can be obtained easily.

According to a fourth aspect of the present invention, a frequency-stabilized light source is provided, which enables the method of the third aspect to be carried out.

The light source includes a semiconductor laser emitting an output light beam, an optical resonator into which the output light beam is injected, a modulator for modulating a temperature of the optical resonator by a modulation signal, a detector for detecting a transmitted light beam through the optical resonator to produce a first output signal, a synchronous detector for synchronously detecting the first output signal with the modulation frequency to produce a second output signal, a controller for controlling an oscillation frequency of the semiconductor laser to keep the frequency at a given value using the second output signal as a signal showing an error in the oscillation frequency.

With the frequency-stabilized light source according to the fourth aspect, the frequency stabilization method of the third aspect is carried out, so that the same effects or advantages as those in the third aspect can be obtained.

According to a fifth aspect of the present invention, a frequency stabilization method of a semiconductor laser is provided, which includes the steps of injecting an output light beam from a semiconductor laser into an optical resonator to produce a transmitted light having a peak frequency of the optical resonator, detecting the transmitted light beam having the peak frequency to produce an output signal about a detected power of the transmitted light beam, controlling the power of the transmitted light beam to be kept constant based on the output signal, and controlling an oscillation frequency of the semiconductor laser to be in accordance with the peak frequency.

With the frequency stabilization method of a semiconductor laser according to the fifth aspect, no gas cell is required, so that only a simple, compact and low-cost setup is sufficient for the method.

Since the power of the transmitted light beam is controlled to be kept constant and at the same time, the oscillation frequency of the laser is controlled to be in accordance with the peak frequency, both of the oscillation frequency and the output light power of the laser can be stabilized.

According to a sixth aspect of the present invention, a frequency-stabilized light source is provided, which enables the method of the fifth aspect to be carried out.

The light source includes a semiconductor laser emitting an output light beam, an optical resonator into which the output light beam is injected, the resonator producing a transmitted light beam and having a peak frequency of the transmitted light beam, a detector for detecting the transmitted light beam to produce an

output signal about a detected power of the transmitted light beam, a first controller for controlling the power of the transmitted light beam to be kept constant based on the output signal, and a second controller for controlling an oscillation frequency of the semiconductor laser to be in accordance with the peak frequency.

With the frequency-stabilized light source according to the sixth aspect, the frequency stabilization method of the fifth aspect is carried out, so that the same effects or advantages as those in the fifth aspect can be obtained.

According to a seventh aspect of the present invention, a frequency-stabilized semiconductor laser module which can carry out the method of the third and fifth aspects is provided.

The module includes a first heat sink whose temperature is controllable, a semiconductor laser mounted on the first heat sink, the semiconductor laser emitting an output light beam, a second heat sink whose temperature is controllable, an optical resonator mounted on the second heat sink, the output light beam being injected into the optical resonator to emit a transmitted light beam from the optical resonator, a detector for receiving the transmitted light beam to detect a power of the transmitted light beam, and a package for incorporating the first heat sink, the semiconductor laser, the second heat sink, the optical resonator and the detector.

With the frequency-stabilized semiconductor laser module according to the seventh aspect, the first heat sink, the semiconductor laser, the second heat sink, the optical resonator and the detector are incorporated in the package, so that the semiconductor laser can operate stably.

Additionally, because the first heat sink for the laser and the second heat sink for the optical resonator are separated, the temperatures of the first and second heat sinks can be set independently. As a result, there is an advantage that the peak frequency of the optical resonator and the oscillation frequency of the laser can be minutely adjusted independently with each other.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a functional block diagram showing a conventional frequency stabilization method of a semiconductor laser.

Fig. 2 is a functional block diagram showing another conventional frequency stabilization method of a semiconductor laser.

Fig. 3 is a functional block diagram of a frequency-stabilized light source according to a first embodiment of the present invention.

Fig. 3A schematically shows a cross section of a semiconductor laser used in the light source shown in Fig. 3.

Fig. 4 is a functional block diagram of a frequency-stabilized light source according to a second embodiment of the present invention.

Fig. 5 is a functional block diagram of a frequency-stabilized light source according to a third embodiment of the present invention.

Fig. 6 is a functional block diagram of a frequency-stabilized light source according to a fourth embodiment of the present invention.

Fig. 7 is a functional block diagram of a frequency-stabilized light source according to a fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described below while referring to the drawings attached.

[First Embodiment]

In Fig. 3, which shows a frequency-stabilized light source according to a first embodiment, a semiconductor laser 101 is mounted on a heat sink 103 through a subcarrier 103a. A photo-detector 115 fixed on the heat sink 103 receives an output light beam of the laser 101 to detect its power and outputs an electrical signal corresponding to the detected power P to a first subtractor 111.

The first subtractor 111 produces by subtraction a difference between the detected power P and the predetermined reference power P_0 and outputs an electrical signal corresponding to the power difference thus produced to a current controller 102. In response to this signal, the current controller 102 controls to increase or decrease a driving current for the laser 101 in order to keep or stabilize the power of the output

light beam at P_0.

A current detector 113 is arranged in a current path between the current controller 102 and the laser 101 to detect the driving current. The current detector 113 outputs an electric signal corresponding to the driving current thus detected to a temperature controller 106. Thus, the driving current is always monitored by the temperature controller 106 during operation.

A voltage detector 114 is electrically connected between input terminals of the laser 101 to detect the voltage therebetween. The voltage detector 114 outputs an electric signal corresponding to the inter-terminal voltage thus detected to the temperature controller 106. Thus, the forward voltage of the laser 101 is always monitored by the temperature controller during operation.

The temperature controller 106 carries out a mathematical operation to get the consumption power of the laser 101 based on the output signals from the current and voltage detectors 113 and 114. Then, the controller 106 increases or decreases the reference temperature T_0 of the heat sink 103 based on the result of the operation and sends an electric signal corresponding to the reference temperature T_0 to a second subtractor 112.

A temperature detector 104 fixed on the heat sink 103 detects the temperature of the heat sink 103. The detector 104 produces an electric signal corresponding to the detected temperature T to send the signal to the second subtractor 112.

The second subtractor 112 produces by subtraction a difference between the detected temperature T and the reference temperature T_0 and outputs an electrical signal corresponding to the temperature difference thus produced to a heat sink controller 105. In response to this signal, the heat sink controller 105 increases or decreases the temperature of the heat sink 103 in order to keep or stabilize the temperature at T_0.

The temperature control by the heat sink controller 105 is carried out using Peltier elements 110 attached to the heat sink 103. Since the Peltier elements 110 generate or absorb heat depending upon its driving current, the temperature of the heat sink 103 can be increased or decreased precisely by the elements 110.

Fig. 3A shows a cross section of the semiconductor laser 101 used in the light source shown in Fig. 3. In Fig. 3A, on the surface of a semiconductor substrate 101a, a strip portion formed of an active layer 101c and upper and lower cladding layers 101d and 101b respectively disposed on upper and lower sides of the active layer 101c. The strip portion is bounded on its each side by a pair of burying layers 101e formed on the surface of the substrate 101a.

A pair of insulator layers 101f are formed on the surfaces of the pair of the burying layers 101e, respectively. An upper electrode or terminal 101g is formed on the surfaces of the insulator layers 101f and the upper cladding layer 101d. A lower electrode or terminal 101h is formed on the back surface of the substrate 101a. The laser 101 is fixed to the subcarrier 103a through the lower electrode 101h.

The pair of the burying layers 101e act as current blocking layers for narrowing the driving current path.

The current detector 113 is electrically connected to the upper electrode 101g and the voltage detector 114 is electrically connected to the upper and lower electrodes 101g and 101h.

Next, the frequency stabilization operation of the semiconductor laser 101 is described below.

The semiconductor laser 101 tends to show a drift or deviation in oscillation frequency in a long period of time when the driving current is controlled so that the output light power of the laser 101 is kept constant and at the same time, the controlling current for the Peltier elements 110 is controlled so that the temperature of the heat sink 103 is kept constant.

It is considered that the drift or deviation in oscillation frequency is caused by change in percentage which contributes the laser oscillation within the total driving current injected into the laser 101. The change in percentage contributing laser oscillation is considered to be caused by (a) increase in leakage current due to deterioration of the current blocking layers or the pair of the burying layers 101e, and by (b) increase in recombination current without luminescence due to deterioration of the active layer 101c.

For example, when both or the output light power and the temperature are kept constant, the driving current percentage contributing laser oscillation tends to decrease, and the driving current increases to compensate the percentage decrease. Thus, the temperature or the active layer 101c rises in response to the increase in the driving current and as a result, the oscillation frequency of the laser 101 will drift toward the lower frequency side.

The drift Δf of the oscillation frequency can be expressed as follows:

It is hardly considered that because an optical loss within the semiconductor laser 101 changes during operation in the long period of time, the carrier density in the laser 101 is kept substantially constant during operation and as a result, the oscillation frequency is not affected by the optical loss. Therefore, it is considered that the frequency change or drift Δf is caused by the temperature change ΔT of the active

layer 101c.

Under the first order approximation, the frequency change Δf can be expressed as

$$\Delta f = \frac{\partial f}{\partial T} \cdot \Delta T \qquad (2)$$

The equation (2) means that the frequency change Δf is zero if the temperature of the active layer 101c is constant, that is, the temperature difference ΔT is zero.

The temperature of the semiconductor laser 101 can be controlled to be kept constant by the heat sink controller 105, however, there arises a temperature difference between the active layer 101c and the heat sink 103 because of heat resistance between the active layer 101c and the temperature detector 104 when the consumption power of the laser 101 changes.

The temperature change ΔT of the active layer 101c is expressed as

$$\Delta T = \theta \cdot \Delta W + \Delta T_0 \qquad (3)$$

where ΔW is the consumption power change of the active layer 101c, θ is the heat resistance between the active layer 101c and the temperature detector 104 and ΔT_0 is the change of the reference temperature of the heat sink 103.

Consequently, it is seen that the temperature change ΔT_0 canbe cancelled if the following equation (4) is established, resulting in a stabilized oscillation frequency.

$$\Delta T_0 = -\theta \cdot \Delta W \qquad (4)$$

Here, the total driving current i_t and the forward voltage v between the input electrodes 101g and 101h can be expressed as the following equations (5a) and (5b) using the initial, total driving current i_{t0}, the initial forward voltage v_0, the change Δi_t of the total driving current i_t,and the change Δv of the forward voltage.

$$i_t = i_{t0} + \Delta i_t \qquad (5a)$$

$$V = V_0 + \Delta V \qquad (5b)$$

From the equations (5a) and (5b), the consumption power change ΔW of the active layer 101c can be expressed as

$$\begin{aligned} \Delta W &= W - W_0 = i_t \cdot v - i_{t0} \cdot v_0 \\ &= \Delta i_t \cdot v_0 + i_{t0} \cdot \Delta v + \Delta i_t \cdot \Delta v \end{aligned} \qquad (6)$$

The reference temperature T_0 of the heat sink 103 is controlled by the heat sink controller 105 so that the consumption power change ΔW expressed by the equation (6) is cancelled.

The temperature controller 106 calculates in value the consumption power change ΔW using the equations (4) and (6) based on the electric signals from the currents and voltage detectors 113 and 114. Then, the controller 106 adjusts in value the reference temperature T_0 to cancel the calculated value of the consumption power change ΔW.

As described above, with the light source according to the first embodiment, the current controller 102 controls the driving current for the semiconductor laser 101 so that the output light power of the laser 101 is kept constant, and at the same time, the temperature controller 106 and the heat sink controller 105 control the reference temperature T_0 of the heat sink 103 so that the temperature change of the active layer 101c is cancelled.

As a result, the oscillation frequency of the laser 101 can be stabilized because of no oscillation frequency drift due to electrical and optical characteristic changes of the laser 101 with passage of time.

Additionally, no gas cell and no synchronous detection means such as a lock-in amplifier are required, so that there arises an advantage that a simple, compact and low-cost setup is sufficient for the light source.

[Second embodiment]

Fig.4 shows a frequency-stabilized light source according to a second embodiment of the present invention. In Fig. 4, the same reference numerals as those in Fig. 3 are attached to the corresponding elements for the sake of simplification of description and illustration.

A current control circuit 216 for controlling the driving current I for the semiconductor laser 101, a temperature control circuit 217 for controlling the temperature of the heat sink 103, and a micro computer 21 for controlling the circuits 216 and 217 are provided instead of the current controller 102, the temperature controller 106 and the heat sink controller 105 in Fig. 3.

The temperature detector 104 sends an electric signal corresponding to the detected temperature T of the heat sink 103 to the micro computer 218. The photodetector 115 sends an electric signal corresponding to the detected light power P of the laser 101 to the micro computer 218. The voltage detector 114 sends an electric signal corresponding to the detected voltage V of the laser 101 to the micro computer 218.

The micro computer 218 is storing data relating the reference power P_0 arid the reference temperature T_0 in advance. The computer 218 calculates data using the signal about the output light power P from the photodetector 115 and sends the data to the current control circuit 216. In response to the data thus sent, the current control circuit 216 controls to supply the driving current to the semiconductor laser 101, so that the output light power from the laser 101 is kept constant.

On the other hand, the computer 218 calculates data using the signals about the forward voltage V from the voltage detector 114 and the temperature T from the temperature detector 104, and sends the data to the temperature control circuit 217. In response to the data thus sent, the temperature control circuit 217 controls to supply the driving current to the Peltier elements 110, so that the reference temperature T_0 of the heat sink 103 is adjusted in order to cancel the temperature change of the active layer 101c.

Therefore, in the second embodiment, the same effects as those the first embodiment can be obtained. Additionally, there is an advantage that the configuration or setup can be made simpler than that of the first embodiment because of the micro computer 218.

[Third Embodiment]

Fig.5 shows a frequency-stabilized light source according to a third embodiment of the present invention.

In Fig. 5, a semiconductor laser 301, which is fixed on a first heat sink 112, emits an output light beam from its one side face and the emitted light beam is injected into an optical fiber 303 optically coupled with the laser 101 through a lens system 302.

A first temperature detector 313 and a first Peltier element 315 are fixed to the first heat sink 312. The detector 313 and the element 315 act to control the temperature of the first heat sink 312 together with a first temperature controller 314, providing the temperature control of the laser 301.

The first temperature controller 314 receives an electric signal about the temperature T_1 of the first heat sink 312 from the first temperature detector 313. On the other hand, the first temperature controller 314 receives an electric signal about the frequency difference or drift Δf from a synchronous detector 316. Based on the signals thus received, the controller 314 controls a driving current for the first Peltier element 315 to increase or decrease the temperature of the first heat sink 312.

Thus, the temperature T_1 of the semiconductor laser 301 is controlled to be kept constant.

Another output light beam of the laser 301 is emitted from its opposite side face and is injected into an optical resonator 304 fixed on a second heat sink 307. The optical resonator 304 is composed of, for example, an optical filter formed of a dielectric multilayer film, a Fabry-Perot etalon or the like. The second heat sink 307 is arranged apart from and adjacent to the first heat sink 312.

The light beam transmitted through the optical resonator 304 goes into a photodetector 305 fixed on the second heat sink 307. The photodetector 305 produces an electric signal corresponding to the detected power P of the light beam and sends the signal to a current controller 406 and the synchronous detector 316.

The current controller 406 controls a driving current I for the laser 301 so that the average output from the photodetector 305 is kept constant.

A second temperature detector 308 and a second Peltier element 310 are fixed to the second heat sink 307. The detector 308 and the element 310 act to control the temperature of the second heat sink 307 together with a second temperature controller 309, providing the temperature control of the optical resonator 304.

The second temperature detector 309 receives an electric signal corresponding to the detected temperature T_2 of the second heat sink 307 from the second temperature detector 308. Based on the signal thus received, the controller 309 controls a driving current for the second Peltier element 310 to increase or decrease the temperature of the second heat sink 307.

The output signal from the second temperature controller 309 is slightly modulated by a modulation signal and is sent to the second Peltier element 310. The modulation signal is supplied from an oscillator 311 and whose frequency is f_m.

Thus, the temperature of the optical resonator 304 is modulated by the modulation signal and at the same time, the temperature T_1 is controlled so that the time average of the temperature T_1 is kept constant

The synchronous detector 316 detects the output signal from the photodetector 305 synchronously with the modulation signal from the oscillator 311. The optical resonator 304 such as a dielectric multilayer film filter or a Fabry-Perot etalon has a peak frequency for the transmitted light beam, which can be approximated by the Lorentz function or Gauss function. In addition, an electric output signal from the synchronous detector 316 has a waveform equal to the primary-differentiated waveform of the transmitted light beam at the peak, frequency, so that the output signal is approximately proportional to the difference Δf between the frequency of the output light beam injected into the optical resonator 304 and the peak frequency of the transmitted light beam through the resonator 304. This means that the electrical output signal from the synchronous detector 316 is available as a signal showing the frequency difference or error Δf.

The output signal from the synchronous detector 316 is sent to the first temperature controller 314. Then, the temperature of the semiconductor laser 301 is controlled by the controller 314 so that the oscillation frequency of the output light beam from the laser 301 is kept in accordance with the peak frequency of the transmitted light beam through the optical resonator 304. As a result, the oscillation frequency of the output light from the laser 301 is kept constant.

In the third embodiment, similar to the first and second embodiments, since no gas cell is necessary, a simple, compact and low-cost light source can be realized. Since the driving current is not modulated, an unmodulated output light can be provided easily.

Also, the semiconductor laser 301, the optical lens system 302, the optical resonator 304, the photodetector 305, the first and second heat sinks 312 and 307, the first, and second temperature detectors 313 and 308, and the first and second Peltier elements 315 and 310 are incorporated into a casing 501, providing a semiconductor laser module. Therefore, there is an advantage of more stable operation and more compact size.

In addition, stabilization in both oscillation frequency and output light power can be realized only by the photodetector 305.

[Fourth Embodiment]

Fig.6 shows a frequency-stabilized light source according to a fourth embodiment, which is the same configuration as that of the third embodiment excepting that the current controller 406 in the third embodiment is omitted.

In the fourth embodiment, in response to the detected power P of the light beam transmitted through the optical resonator 304, the photodetector 305 produces an electric signal corresponding to the detected power P and sends the signal only to the synchronous detector 316. The driving current I for the laser 301 is not controlled because of no currents controller.

Since the driving current I for the semiconductor laser 301 is not controlled, the power of the output light beam from the laser 301 does not necessarily stabilized, however, there is an advantage that the configuration becomes simpler than that of the third embodiment.

[Fifth Embodiment]

Fig.7 shows a frequency-stabilized light source according to a fifth embodiment, in which the temperature of the semiconductor laser 301 is controlled so that the output light power of the laser 301 is kept constant and the driving current for the laser 301 is controlled so that the oscillation frequency of the output light beam is kept constant.

In Fig. 7, the same reference numerals as those in Fig. 5 are attached to the corresponding elements for the sake of simplification of description and illustration.

Different from the third embodiment in Fig. 5, a current controller 606 is arranged between the synchronous detector 316 and the semiconductor laser 301.

The first temperature controller 314 receives an electric signal corresponding to the temperature T_1 of the first heat sink 312 from the first temperature detector 313. On the other hand, the first temperature controller 314 receives an electric signal corresponding to the output light power P from the photodetector 305. Based on the signals thus received, the controller 314 controls the driving current for the first Peltier element 315 to increase or decrease the temperature of the first heat sink 312.

Thus, the output light power of the semiconductor laser 301 is controlled to be kept constant.

The electrical output signal corresponding the detected power P of the output light, which is outputted from the photodetector 305, is sent to the synchronous detector 316. The detector 316 detects the signal thus sent synchronously with the modulation frequency f_m from the oscillator 311 and produces an electric signal proportional to the frequency difference Δf. The signal thus produced is then sent to the current controller 606.

The output signal from the second temperature controller 309 is slightly modulated by a modulation signal whose frequency is f_m and is sent to the second Peltier element 310.

The current controller 606 controls a driving current I for the laser 301 so that the oscillation frequency of the laser 301 is kept constant.

Thus, the temperature of the optical resonator 304 is modulated by the modulation signal from the oscillator 311 and at the same time, the temperature is controlled so that the time average of the temperature is kept constant.

In the fifth embodiment, the same effects or advantages as those in the third embodiment can be obtained.

In the present invention, any control means such as analog control means using the PID control method, digital control means using micro computers or the like can be employed as the controllers above described.

It is needless to say that the present invention is not restricted to the above first to fifth embodiments, and any other variations can be made.

Claims

1. A frequency stabilization method of a semiconductor laser, said method comprising the steps of:
   detecting an output light power of a semiconductor laser mounted on a heat sink;
   obtaining a consumption power of said laser;
   obtaining a relationship between said output light power and said consumption power;
   detecting a temperature of said heat sink;
   controlling a driving current for the laser so that said output light power is kept constant; and
   controlling said temperature of said heat sink based on said relationship so that a temperature of an active layer of said laser is maintained.

2. A frequency stabilization method of a semiconductor laser as claimed in claim 1, further comprising the steps of:
   detecting said driving current of said semiconductor laser; and
   detecting a voltage drop of said laser;
   wherein said relationship between said output light power and said consumption power is obtained based on detection results of said driving current and said voltage.

3. A frequency-stabilized light source, comprising:
   a light power detector for detecting an output light power of a semiconductor laser mounted on a heat sink;
   a first operator for obtaining a consumption power of said laser;
   a second operator for obtaining a relationship between said output light power and said consumption power;
   a temperature detector for detecting a temperature of said heat sink;
   a first controller for controlling said driving current so that said output light power is kept constant; and
   a second controller for controlling said temperature of said heat sink based on said relationship so that a temperature of an active layer of said laser is maintained.

4. A frequency-stabilized light source as claimed in claim 3, further comprising:
   a current detector for detecting said driving current of said semiconductor laser; and

a voltage detector for detecting a voltage drop of said laser;

wherein said relationship between said output light power and said consumption power is obtained based on detection results of said driving current and said voltage.

5. A frequency stabilization method of a semiconductor laser, said method comprising the steps of:

injecting an output light beam from a semiconductor laser into an optical resonator;

modulating a temperature of said optical resonator by a modulation signal;

detecting a transmitted light beam through said optical resonator to produce a first output signal;

synchronously detecting said first output signal with said modulation frequency to produce a second output signal;

controlling an oscillation frequency of said semiconductor laser to keep said frequency at a given value using said second output signal as a signal showing an error in said oscillation frequency.

6. A frequency stabilization method of a semiconductor laser as claimed in claim 5, wherein, said oscillation frequency of said semiconductor laser is controlled to be in accordance with a peak frequency of said optical resonator in said step of controlling an oscillation frequency.

7. A frequency stabilization method of a semiconductor laser as claimed in claim 5, wherein, said semiconductor laser is mounted on a first heat sink and is controlled to be a constant temperature, and wherein said optical resonator is mounted on a second heat sink and said temperature of said optical resonator is modulated through said second beat sink.

8. A frequency stabilization method of a semiconductor laser as claimed in claim 5, wherein, a driving current for said semiconductor laser is controlled so that an output light power from said laser is kept constant.

9. A frequency stabilization method of a semiconductor laser as claimed in claim 5, wherein, a temperature of said semiconductor laser is controlled so that an output light power from said laser is kept constant.

10. A frequency stabilization method of a semiconductor laser as claimed in claim 5, wherein, a driving current for said semiconductor laser is controlled so that said oscillation frequency of said laser is kept at a given value.

11. A frequency stabilization method of a semiconductor laser as claimed in claim 5, wherein, a temperature of said semiconductor laser is controlled so that said oscillation frequency of said laser is kept at a given value.

12. A frequency-stabilized light source comprising:

a semiconductor laser emitting an output light beam;

an optical resonator into which said output light beam is injected;

a modulator for modulating a temperature of said optical resonator by a modulation signal;

a detector for detecting a transmitted light beam through said optical resonator to produce a first output signal;

a synchronous detector for synchronously detecting said first output signal with said modulation frequency to produce a second output signal;

a controller for controlling an oscillation frequency of said semiconductor laser to keep said frequency at a given value using said second output signal as a signal showing an error in said oscillation frequency.

13. A frequency-stabilized light source as claimed in claim 12, wherein, said oscillation frequency of said semiconductor laser is controlled to be in accordance with a peak frequency of said optical resonator.

14. A frequency-stabilized light source as claimed in claim 12, wherein, said semiconductor laser is mounted on a first heat sink and is controlled to be a constant temperature, and wherein said optical resonator is mounted on a second heat sink and said temperature of said optical resonator is modulated through said second heat sink.

15. A frequency-stabilized light source as claimed in claim 12, wherein, a driving current for said semiconductor laser is controlled so that an output light power from said, laser is kept constant.

16. A frequency-stabilized light source as claimed in claim 12, wherein, a temperature of said semiconductor laser is controlled so that an output light power from said laser is kept constant.

17. A frequency-stabilized light source as claimed in claim 12, wherein, a driving current for said semiconductor laser is controlled so that said oscillation frequency of said laser is kept at a given value.

18. A frequency-stabilized light source as claimed in claim 12, wherein, a temperature of said semiconductor laser is controlled so that said oscillation frequency of said laser is kept at a given value.

19. A frequency stabilization method of a semiconductor laser; said method comprising the steps of:

injecting an output light beam from a semiconductor laser into an optical resonator to produce a transmitted light having a peak frequency of said optical resonator;

detecting said transmitted light beam having said peak frequency to produce an output signal about a detected power of said transmitted light beam;

controlling said power of said transmitted light beam to be kept constant based on said output signal; and

controlling an oscillation frequency of said semiconductor laser to be in accordance with said peak frequency.

20. A frequency-stabilized light source comprising:

a semiconductor laser emitting an output light beam;

an optical resonator into which said output light beam is injected;

said resonator producing a transmitted light beam and having a peak frequency of said transmitted light beam;

a detector for detecting said transmitted light beam to produce an output signal about a detected power of said transmitted light beam;

a first controller for controlling said power of said transmitted light beam to be kept constant based on said output signal; and

a second controller for controlling an oscillation frequency of said semiconductor laser to be in accordance with said peak frequency.

21. A semiconductor laser module comprising:

a first heat sink whose temperature is controllable;

a semiconductor laser mounted on said first heat sink;

said semiconductor laser emitting an output light beam;

a second heat sink whose temperature is controllable;

an optical resonator mounted on said second heat sink;

said output light beam being injected into said optical resonator to emit a transmitted light beam from said optical resonator;

a detector for receiving said transmitted light beam to detect a power of said transmitted light beam; and

a package for incorporating said first heat sink; said semiconductor laser; said second heat sink; said optical resonator and said detector.

22. A semiconductor laser module as claimed in claim 21, wherein,

a temperature of said optical resonator is modulated by a modulation signal;

a transmitted light beam through said optical resonator is used to produce a first output signal;

a power of said transmitted light beam is controlled to be kept constant based on said first output signal;

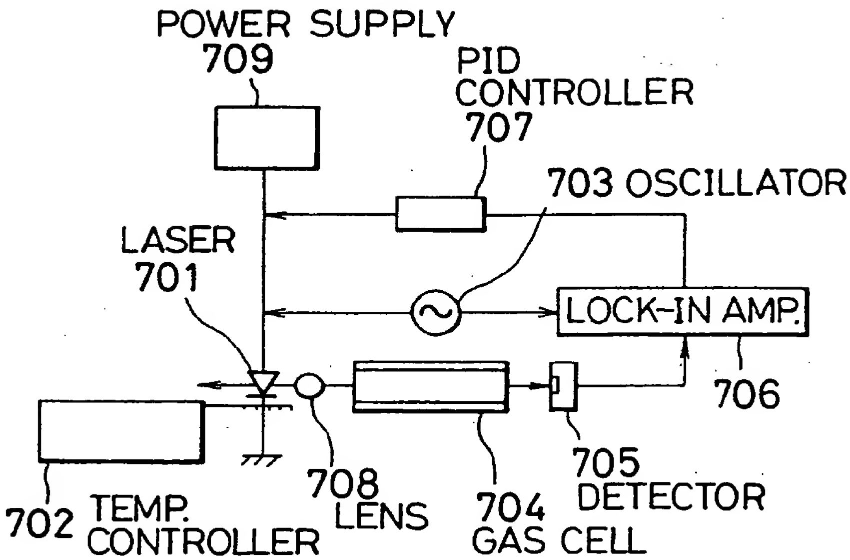
said first output signal is synchronously detected with said modulation frequency to produce a second output signal; and

an oscillation frequency of said semiconductor laser is controlled to keep said frequency at a given value using said second output signal as a signal showing an error in said oscillation frequency.

23. A semiconductor laser module as claimed in claim 22, wherein, said oscillation frequency of said semiconductor laser is controlled to be in accordance with a peak frequency of said optical resonator in said step of controlling an oscillation frequency.

24. A semiconductor laser module as claimed in claim 22, wherein, said semiconductor laser is controlled to be a constant temperature through said first heat sink, and said optical resonator is modulated through said second heat sink.

F I G. 1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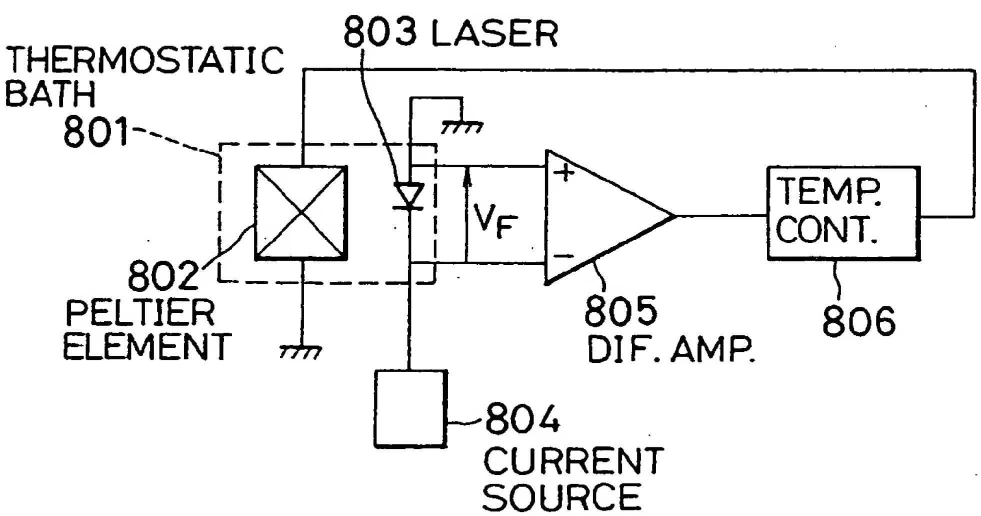
CONTROLLER

F I G. 2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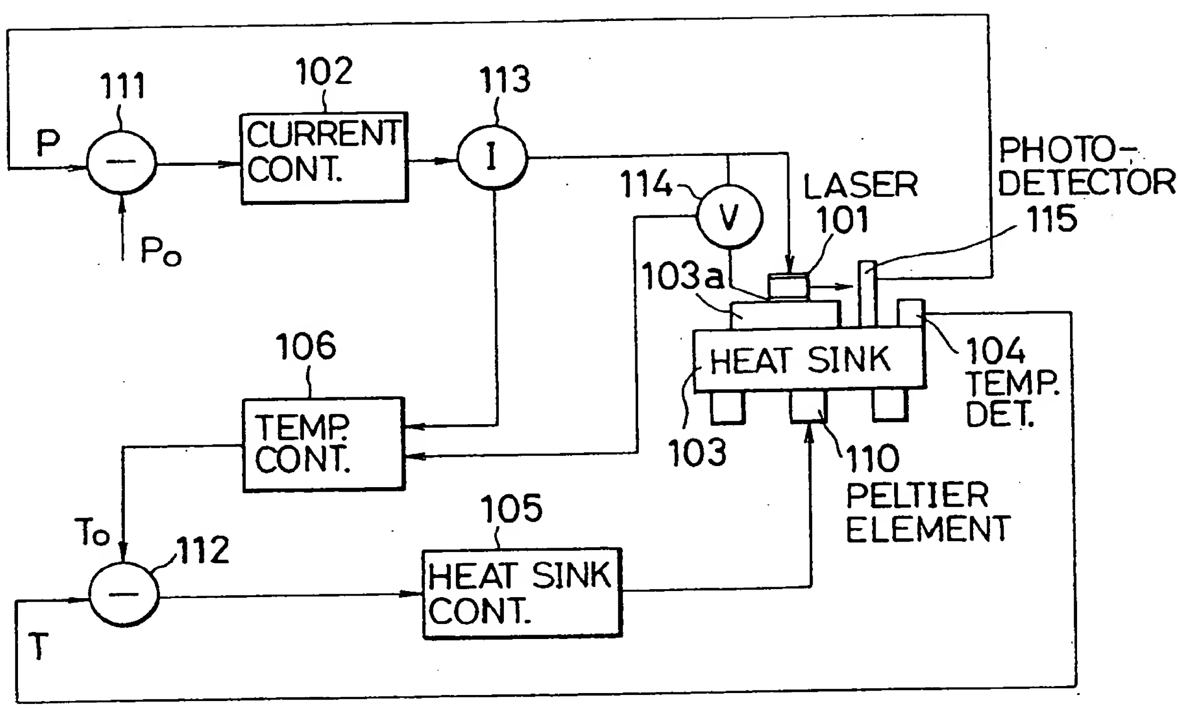
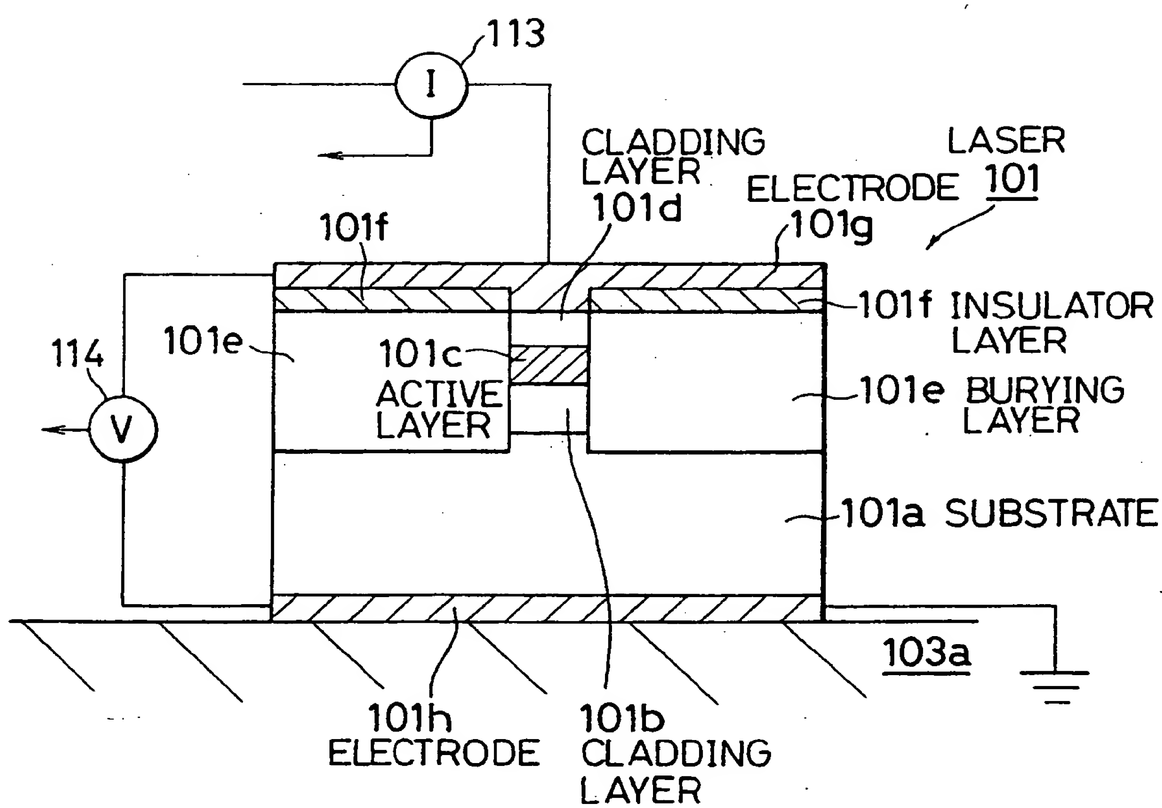
CURRENT
SOURCE

F I G. 3


111
102
113
P
CURRENT CONT.
I
Po
114
V
LASER 101
PHOTO-DETECTOR 115
103a
HEAT SINK
104 TEMP. DET.
106
TEMP. CONT.
103
110 PELTIER ELEMENT
105
To
112
HEAT SINK CONT.
T

F I G. 3A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103a
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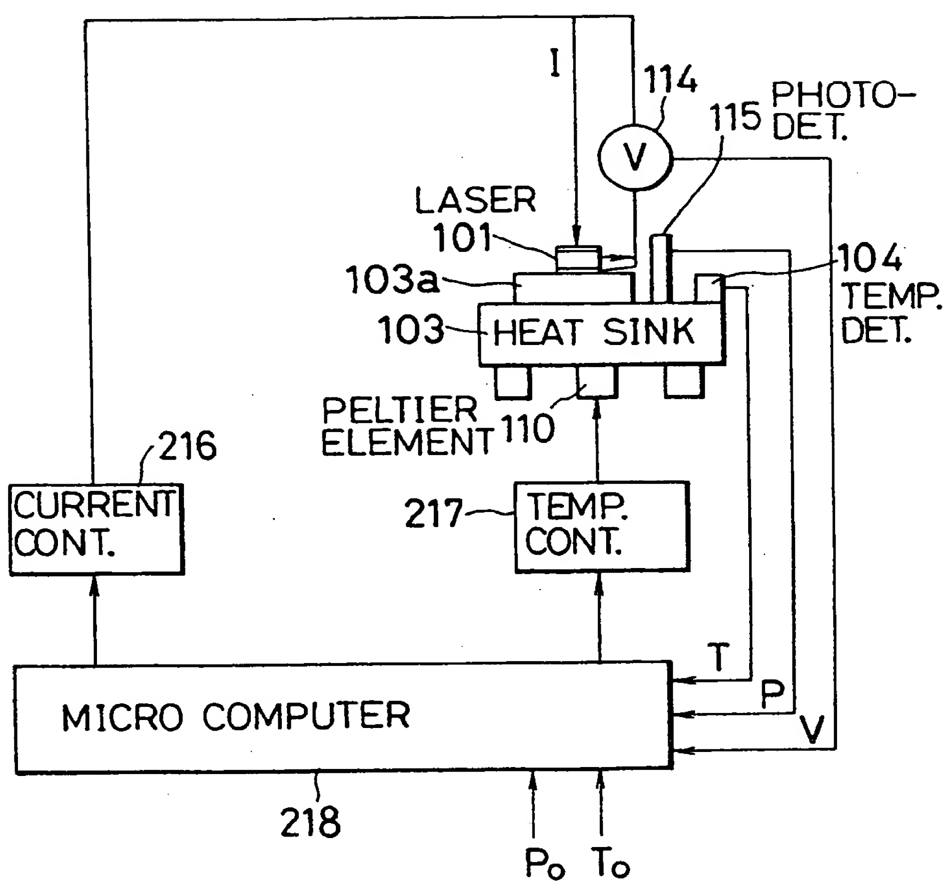
101b CLADDING LAYER

F I G. 4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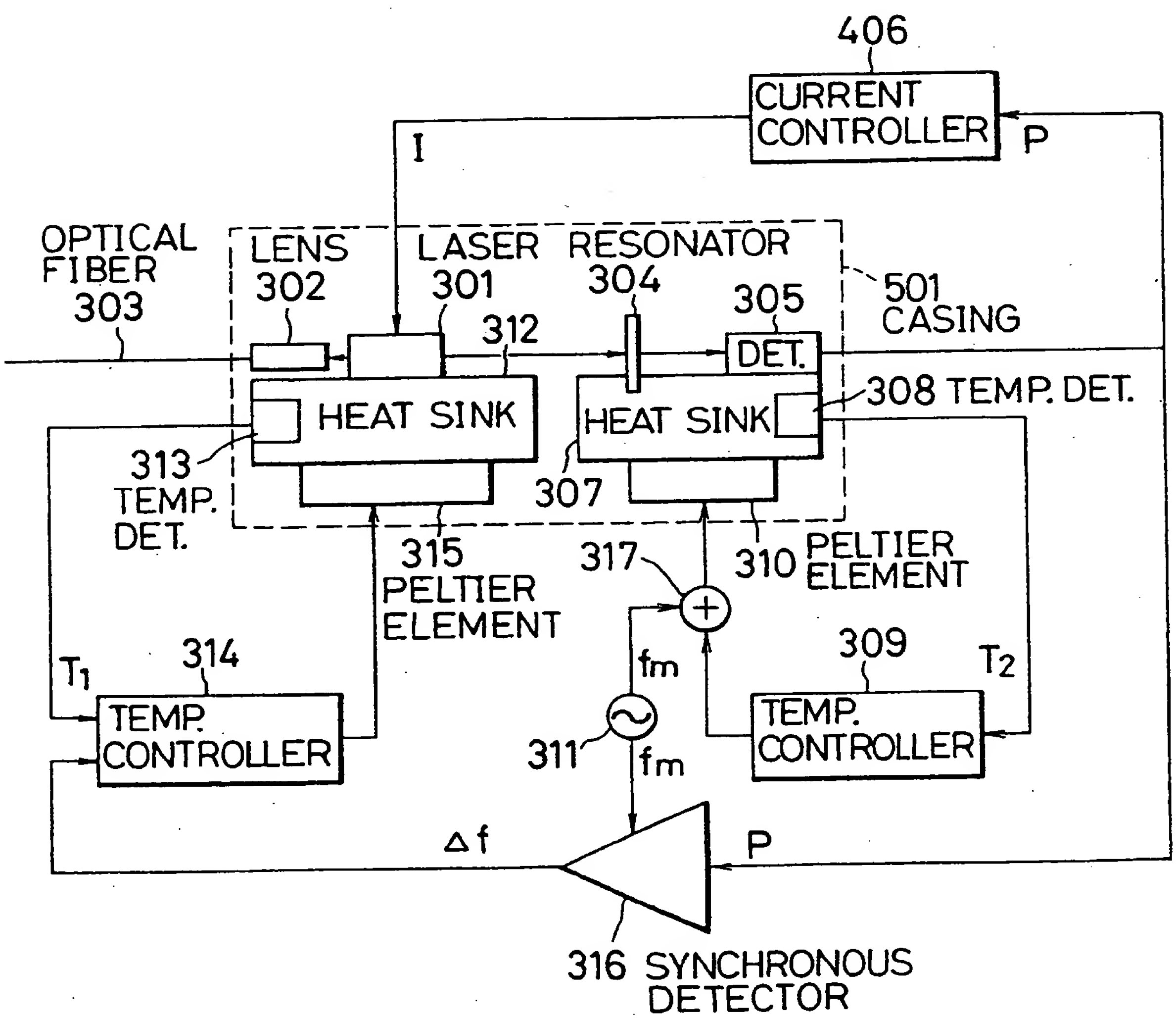
V
MICRO COMPUTER
218
Po
To

FIG. 5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T1
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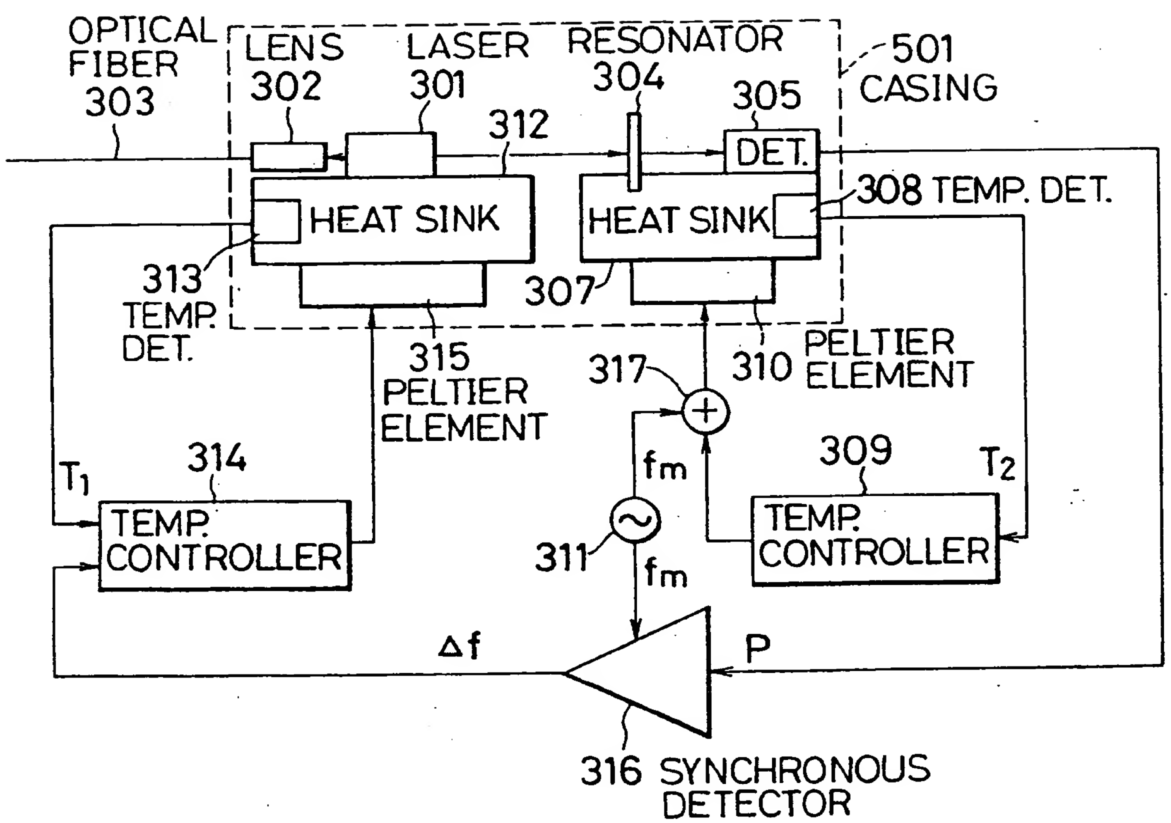
316 SYNCHRONOUS DETECTOR

F I G. 6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313
TEMP. DET.
307
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PELTIER ELEMENT
317
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PELTIER ELEMENT
fm
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311
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309
T_2
TEMP. CONTROLLER
Δf
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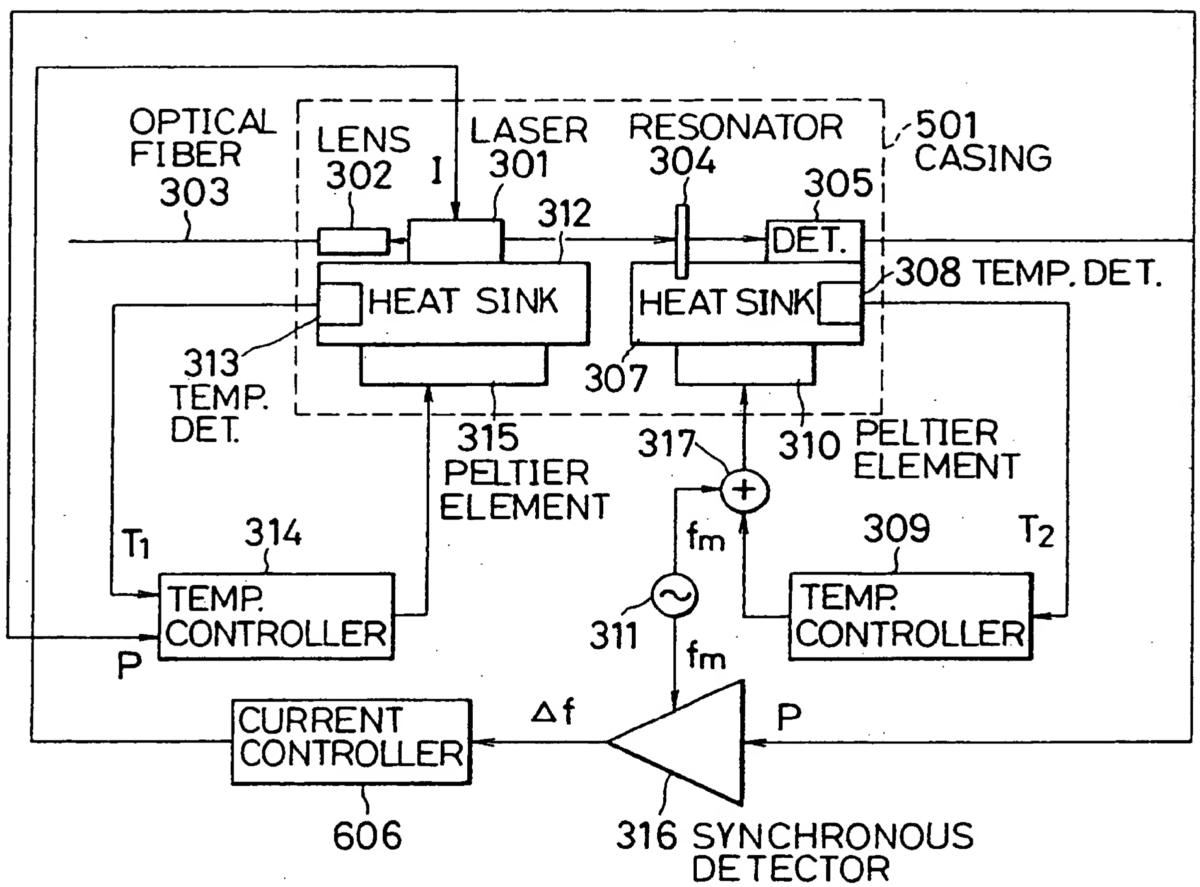
316 SYNCHRONOUS DETECTOR

FIG. 7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307
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+
T1
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fm
309
T2
TEMP. CONTROLLER
TEMP. CONTROLLER
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CURRENT CONTROLLER
Δf
P
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316 SYNCHRONOUS DETECTOR

(19) Europäisches Patentamt
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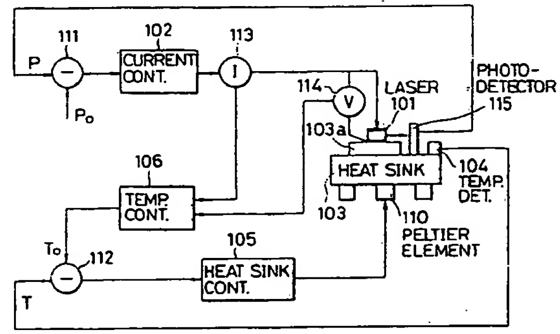
(54) **Frequency stabilization method of semiconductor laser, frequency-stabilized light source and laser module.**

(57) A frequency stabilization method of a semiconductor laser is provided. A driving current, a forward voltage and an output light power of the laser mounted on a heat sink is detected. A temperature of the heat sink is also detected. A consumption power of the laser is obtained from the driving current and voltage thus detected, providing a relationship between the output light power and the consumption power. The driving current is controlled so that the output light power is kept constant, and the temperature of the heat sink is controlled based on the relationship so that a temperature of an active layer of the laser is maintained. The output light power is kept constant and at the same time, any temperature change of the active layer is cancelled through the temperature control of the heat sink. Even if the consumption power changes due to an leakage current and/or a recombination current without luminescence to maintain the output light power during long time operation, the temperature of the active layer is maintained by cancelling the consumption power change through the temperature control of the heat sink. Thus, the oscillation frequency of the semiconductor laser can be stabilized at a given value.

F I G. 3



EP 0 618 653 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 10 5059

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	US-A-4 821 273 (HORI) 11 April 1989 * the whole document * ---	1-4	H01S3/133 H01S3/043 H01S3/025
A	GB-A-2 224 374 (THE PLESSEY COMPANY) 2 May 1990 * the whole document * ---	1-4	
A	PATENT ABSTRACTS OF JAPAN vol. 5, no. 159 (E-77) (831) 14 October 1981 & JP-A-56 090 583 (RICOH) 22 July 1981 * abstract * ---	1-4	
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 123 (E-249) 8 June 1984 & JP-A-59 034 684 (HITACHI DENSEN) 25 February 1984 * abstract * ---	1	
A	US-A-4 695 714 (KIMIZUKA ET AL.) 22 September 1987 * column 1, line 18 - line 41 * * column 1, line 66 - column 2, line 47 * * column 4, line 51 - column 5, line 16; figure 1 * ---	1-4	**TECHNICAL FIELDS SEARCHED (Int.Cl.5)** H01S H04B
A	US-A-4 583 228 (BROWN ET AL.) 15 April 1986 * the whole document * --- -/--	1,6,10, 11,13, 17,18,23	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 January 1995	Stang, I

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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& : member of the same patent family, corresponding document

European Patent
Office

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- [ ] All claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for all claims.
- [ ] Only part of the claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid,

  namely claims:
- [ ] No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions.

namely:

see sheet -B-

- [x] All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- [ ] Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid.

  namely claims:
- [ ] None of the further search fees has ~~been~~ paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims,

  namely claims:

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 10 5059

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, vol.36, no.3, September 1987, NEW YORK, US pages 789 - 796 S.YAMAGUCHI ET AL. 'Power Level Controlled Optical Sweep Oscillator Using a GaAs Semiconductor Laser' * paragraphs IIA, IIB, IVB, IVD * * figure 1 *	5-24	
A	ELECTRONICS LETTERS, vol.26, no.6, 15 March 1990, STEVENAGE. GB pages 405 - 406, XP122770 M.S.NAKAMURA ET AL. 'Frequency-Stabilized LD Module with a Z-Cut Quartz Fabry-Perot Resonator for Coherent Communication' * the whole document *	5-8,10, 12-15, 17,19, 20,22,23	
A	ELECTRONICS LETTERS, vol.22, no.10, 8 May 1986, STEVENAGE, GB pages 553 - 554 H.TSUCHIDA ET AL. 'Wideband Frequency Scanning of a Stabilised Semiconductor Laser' * the whole document *	5-8,10, 12-15, 17,19-21	TECHNICAL FIELDS SEARCHED (Int.Cl.5)
A	JAPANESE JOURNAL OF APPLIED PHYSICS, vol.19, no.12, December 1980, TOKYO, JP pages L721 - L724 H.TSUCHIDA ET AL. 'Frequency Stability Measurement of Feedback Stabilized AlGaAs DH Laser' * paragraph 2; figure 1 *	5-7, 11-14, 18,21, 23,24	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 January 1995	Stang, I

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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EUROPEAN SEARCH REPORT

Application Number
EP 94 10 5059

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	EP-A-0 336 308 (CSELT CENTRO STUDI E LABORATORI TELECOMUNICAZIONI) 11 October 1989 * column 2, line 39 - column 3, line 3 * * column 4, line 35 - column 5, line 56; figures 1,2 * ---	5,6,10, 12,13, 17,22,23	
A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 403 (E-674) (3250) 26 October 1988 & JP-A-63 143 888 (YOKOGAWA ELECTRIC) 16 June 1988 * abstract * ---	11,18,24	
A	PATENT ABSTRACTS OF JAPAN vol. 14, no. 336 (E-0953) 19 July 1990 & JP-A-02 112 295 (YOKOGAWA ELECTRIC) 24 April 1990 * abstract * -----	21	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 January 1995	Stang, I

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EP 94 10 5059 -B-

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirement of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims 1-4 :

   A frequency stabilization method of a semiconductor laser is performed by the simultaneous detection of the laser output power and the laser consumption power and by establishing a relationship between both in order to keep constant the temperature of the active layer.

2. Claims 5-18,21-24 :

   Frequency stabilization method of a semiconductor laser in which the laser output is transmitted through a temperature modulated optical resonator and then synchronously detected with the modulation frequency whereby an oscillating frequency error signal is obtained.

3. Claims 19-20 :

   Frequency stabilization method of a semiconductor laser where the output of the laser is transmitted through an optical resonator and this transmitted light is detected in order to control the power of the transmitted light beam to be constant.

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(54) **Optical wavelength stability control apparatus and optical transmitter**

(57) An optical transmitter includes a plurality of optical wavelength stability control apparatus, each of which is capable of compensating a wavelength drift by varying the laser diode drive current. Each of the optical wavelength stability control apparatus detects the laser diode drive current, which is controlled by an auto power control circuit, by using a laser diode drive current detector (1). The laser diode drive current is normalised by a laser diode drive current increase/decrease normalisation unit (2). A laser diode temperature control target value is generated at a compensated reference voltage generator (3a, 3b), in response to the normalised laser diode drive current, to control the current value applied to a thermoelectric cooler (12) so that the output value of a temperature monitor circuit (10) approaches a predetermined laser diode temperature control target value.

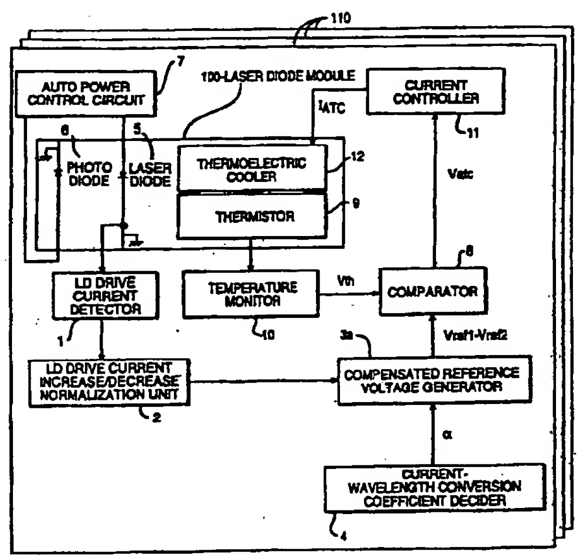

FIG. 1

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Description

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

[0001] The present invention relates to an optical wavelength stability control apparatus for stabilizing an optical wavelength output from a laser diode (hereinafter, LD). In particular, the present invention relates to an optical wavelength stability control apparatus suitable for an optical multiple wavelength transmission.

2. DESCRIPTION OF THE RELATED ART

[0002] Due to the development of an advanced information society, an optical communication system to which an optical signal is transmitted by using an optical fiber requires an enlarged transmission capacity. The optical multiple wavelength transmission is implemented to realize an increase in transmission capacity. A plurality of channels are transmitted through a common transmission path by assigning respective signals to different optical wavelengths. The precision stabilization of the optical wavelength within ±0.2 nm has long been required so that adjacent wavelengths do not interfere with each other.

[0003] FIG. 2 illustrates a conventional apparatus for optical wavelength stabilization. In general, it is known that a temperature fluctuation as well as a drive current fluctuation of a semiconductor laser cause a fluctuation of the optical transmitter. FIG. 2 illustrates an apparatus used for stabilizing an optical wavelength by keeping the temperature of a semiconductor laser 5 constant. A temperature monitor 10 detects the temperature of LD using a thermistor 9 and a reference voltage generator 3b outputs a reference temperature voltage which is a target value for controlling a temperature. An output voltage (Vth) of the temperature monitor 10 and an output voltage (Vref1) of the reference voltage generator 3b are compared at a comparator 8, and the difference between Vth and Vref1 is calculated. In a current controller 11, the stabilization of the optical wavelength is done by determining a drive current value of a thermoelectric cooler 12 so that an output value at the comparator 8 becomes zero. A semiconductor laser apparatus described in a Japanese laid-open patent No 57-186383 also employs the same method.

[0004] However, the electric power consumption (an input electric power to the semiconductor laser) required to obtain the identical optical power output gradually increases over time with the age of a semiconductor laser. Thus, the temperature at an active layer of the semiconductor laser rises and thereby causes an optical wavelength to fluctuate.

[0005] Japanese laid open patent 6-283797 describes a control method for keeping an optical power output and the temperature of the active layer constant. According to this method the temperature of a heat sink is controlled to negate a temperature rise of the active layer caused by an increase of the electric power consumption to gain an identical optical power with respect to an age related change of the semiconductor laser. Based upon this control, the temperature of the laser can be constantly controlled for a long period of time.

[0006] However, even if the temperature of the laser could be made constant, there is a problem that the optical wavelength of the laser changes in accordance with the fluctuation of the drive current when it is varied. In other words, as shown in FIG. 3, efficiency decreases with the age of the LD. To compensate for this deterioration, the LD drive current is controlled by an auto power control circuit (hereinafter, APC) so that the optical output of the LD becomes constant. Therefore, as shown in FIG. 4, the LD drive current value If (t) increases. The relation between optical wavelength and LD drive current is shown in FIG. 5.

[0007] Then, the fluctuation of the LD drive current causes fluctuation of the wavelength. A timing chart of an operation and a wavelength fluctuation in the conventional art is shown in FIGS. 6(a)-6(d).

[0008] When the LD drive current If (t) fluctuates with respect to an aging deterioration as shown in FIG. 6(a), a quantity of the wavelength fluctuation increases and the fluctuation cannot be compensated because a reference voltage (Vref1) is a fixed value as shown in FIG. 6(b).

[0009] The above-mentioned characteristics are explained using the following equations. A quantity of the wavelength drift ($\Delta\lambda 1$) causing an increase/decrease of the LD drive current is given as equation 1.

$$\Delta\lambda 1 = \alpha \cdot \{If(tn)-If(t0)\} \tag{1}$$

where

α = Drive current-wavelength fluctuation conversion constant,

$If(t0)$ = Drive current value at initial time t0, and

If(tn) = Drive current after passing time tn.

[0010] On the other hand, a quantity of the wavelength drift ($\Delta\lambda 2$) caused by a control loop error of a current controller is given as equation 2.

$$\Delta\lambda 2 = (1/G) \cdot Vatc \cdot \beta \cdot \gamma \quad (2),$$

where

G = Feedback loop gain,

Vatc = Normalization portion output voltage value,

β = Temperature of the laser - Wavelength conversion constant, and

γ = Temperature in a circuit - Voltage conversion constant.

[0011] Accordingly, a quantity of the wavelength drift ($\Delta\lambda$) in the optical wavelength stability control method of the conventional art is given as equation 3.

$$\Delta\lambda = \Delta\lambda 1 + \Delta\lambda 2 = \alpha \cdot \{If(tn)-If(t0)\}+(1/G) \cdot Vatc \cdot \beta \cdot \gamma \quad (3)$$

[0012] Equation 4 is obtained from a feedback stability condition.

$$Vatc = G \cdot (Vth-Vref1) \quad (4)$$

where

Vth = Temperature monitor output (LD temperature), and

Vref = Reference voltage generator output (initial set temperature).

[0013] When the equation 4 is substituted into the equation 3, $\Delta\lambda$ is given as equation 5.

$$\Delta\lambda = \alpha \cdot \{If(tn)-If(t0)\}+(Vth-Vref1) \cdot \beta \cdot \gamma \quad (5)$$

[0014] From the equation 5, it is confirmed that it is impossible to compensate the wavelength drift $\alpha \cdot \{If(tn)-If(t0)\}$ causing an increase/decrease of the LD drive current, even though the thermal detection voltage Vth and the reference voltage Vref 1 can be controlled.

SUMMARY OF THE INVENTION

[0015] An object of the present invention is to provide an optical wavelength stability control apparatus for stabilizing the wavelength precisely by compensating for the wavelength drift over a long period of time.

[0016] An object of the present invention is to provide an optical wavelength stability control apparatus for stabilizing the optical wavelength output from a LD. This apparatus includes a current detector for detecting the LD drive current driving the LD, and a thermal controller including a compensated reference voltage generator 3a, a comparator 8, a thermistor 9, a temperature monitor 10, a current controller 11 and a thermoelectric cooler 12, for controlling a temperature of the LD to be a control target value. The thermal controller includes a reference generator means for setting the control target value in response to the LD drive current detected by the current detector.

[0017] Another object of the present invention is to provide an optical transmitter including a plurality of optical wavelength stability control apparatus, each of the optical wavelength stability control apparatus including a laser diode module having the LD, a photo-diode (hereinafter, PD), a thermoelectric cooler and a thermistor built-in. The apparatus includes an APC capable of controlling the stability of the optical power output by varying the LD drive current driving the LD,

a LD drive current detector for detecting the LD drive current,

a LD drive current increase/decrease normalization unit for outputting the increased or decreased LD drive current value being normalized, based upon the detected LD drive current value,

a compensated reference voltage generator for generating the LD temperature control target value in response to an increase or a decrease of the LD drive current value being normalized,

a temperature monitor circuit for detecting a temperature of the LD based on the thermistor,

a comparator for detecting a difference between the detected LD temperature value and the LD temperature control target value,

a current controller for determining a current value applied to the thermoelectric cooler so that a value detected by the comparator becomes zero, and

a thermoelectric cooler for applying to the thermoelectric cooler a current value determined by the current controller.

[0018] Yet another object of the present invention is to provide a method for stabilizing an optical wavelength output from a LD using a leading discharge at a diode connection portion. The method encompasses detecting a fluctuation of a drive current driving a LD and regulating a temperature at a diode connection portion to compensate the fluctuation of an optical wavelength along with a variation of the LD drive current.

[0019] Still another object is to provide an optical multiple wavelength transmitter for transmitting light having a plurality of different wavelengths. The transmitter includes a plurality of optical wavelength stability control apparatus, each of which includes:

a LD,

a current detector for detecting respectively the drive current driving the LD, and

means for controlling respectively the temperature of the LD,
wherein the means for controlling includes a temperature detection means for detecting respectively the temperature of the LD, a cooling means for cooling respectively the LD and a control means for setting respectively a control target temperature for the respective LD using a conversion coefficient predetermined for the respective LD in response to the variation of the detected drive current and controlling the cooling means to regulate the detected respectively the temperature of the LD to a set control target value.

[0020] Alternatively, the transmitter may include a plurality of laser diode modules and a common current detector and a common means for controlling the temperatures of the laser diodes.

[0021] These and other objects, features and advantages of the present invention will be readily apparent in view of the following detailed description of the preferred embodiments in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

FIG. 1 illustrates an optical wavelength stability control apparatus based upon the present invention;

FIG. 2 illustrates the inventors analysis of a conventional optical wavelength stabilization control apparatus;

FIG. 3 is a graph showing the relation between the characteristics of an electrical/optical conversion and time for the LD;

FIG. 4 is a graph showing the relation between the LD drive current and time for compensating the deterioration of the LD;

FIG. 5 is a graph showing the relation between a drive current and a quantity of the wavelength drift for the LD;

FIGS. 6(A)-6(D) are timing charts showing wavelength drift that occurs in the prior art; and

FIG. 7 is a timing chart showing a wavelength drift and an operation in the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] A description will be given of the embodiments of the present invention by reference to the accompanying drawings.

[0024] FIG. 1 shows an example of a plurality of optical wavelength stability control apparatuses 110 used in an optical transmitter. Each of the apparatus includes a laser diode module 100 having a LD 5, a PD 6, a thermoelectric cooler 12 and a thermistor 9, a APC 7, a LD drive current detector 1, a LD drive current increase/decrease normalization unit 2, a compensated reference voltage generator 3a, a current-wavelength conversion coefficient decider 4, a comparator 8, a temperature monitor 10 and a current controller 11. A plurality of such apparatuses are used to form the optical transmitter. Each of the apparatuses has a LD outputting a respective optical wavelength. While FIG. 1 illustrates an embodiment where each apparatus 110 is provided with a plurality of elements as shown, according to another embodiment, the transmitter may only have a plurality of laser diode modules, while the remaining elements are commonly provided.

[0025] A thermal controller controls the temperature of the laser diode to be a control target value. According to the disclosed embodiment, the thermal controller includes thermoelectric cooler 12, thermistor 9, temperature monitor 10, comparator 8, compensated reference voltage generator 3a, current-wavelength conversion coefficient decider 4 and current controller 11. Of course, numerous variations could be made to the thermal controller shown in order to achieve the same objective of controlling temperature based upon measured laser diode current.

[0026] The PD 6 is used to detect an intensity of an optical power from the LD.

[0027] A thermoelectric cooler 12 is used to cool the LD 5 by discharging heat from the LD 5 to outside of the laser diode module 100. On the other hand, the thermoelectric cooler 12 transfers heat in the reverse direction, thereby causing the LD 5 to absorb heat from outside of the module 100.

[0028] A portion of light outputted from the LD 5 is branched to the PD 6 and an intensity of the optical power is detected. The APC 7 controls the drive current value so that the power output value detected by the PD 6 becomes a constant. The detected power output is proportional to the optical output power of the LD 5 because the optical power output is branched at a constant ratio. Accordingly, the optical output power from the LD 5 is stabilized by controlling the drive current value.

[0029] The LD drive current increase / decrease normalization unit 2 normalizes a deviation of the drive current from an initial value, and outputs such deviation as a standard value. This standard value is input to the compensated reference voltage generator 3a.

[0030] The compensated reference voltage generator 3a generates a temperature setting value correcting an optical wavelength drift due to deterioration caused by aging of the LD, based upon an input standard value and a current-wavelength conversion coefficient α input from a current-wavelength conversion coefficient decider 4. The temperature setting value (Vatc) is output to the comparator 8.

[0031] The comparator 8 detects a difference between the temperature setting value from the compensated reference voltage generator 3a and a temperature of the LD detected by the thermistor 9.

[0032] The current controller 11 determines the current value for driving the thermoelectric cooler 12 so that the difference detected by the comparator 8 becomes small (even zero, for example) thereby controlling the stability of an optical wavelength of the LD 5.

[0033] With reference to FIG. 1 and 7, the details for the optical wavelength stability control are described.

[0034] An optical wavelength stability control apparatus increases the LD drive current with the APC 7 so as to keep the optical power output constant when the LD 5 deteriorates.

[0035] An increased quantity of the LD drive current is detected for every (Tx+Ty) seconds, output as a normalized value, If (tn) - If (t0) via the LD drive current detector 1 and the LD drive current increase / decrease normalization unit 2.

Tx : the sampling time for calculating a mean value of the LD drive current.

Ty : the waiting time. A drive current is sampled by Ty.

If (tn) : the mean value of the drive current detected in a sampling time Tx.

If (t0) : the initial value of the drive current.

[0036] The compensated reference voltage generator 3a calculates a voltage Vref2 to correct an optical wavelength drift share based on the normalized increased value of the drive current and the current -wavelength conversion coefficient α. The voltage generator 3a outputs the compensated reference voltage Vref1 - Vref2 to the comparator 8.

[0037] The comparator 8 compares the detected temperature of the LD (Vth) with the compensated reference voltage

(Vref1-Vref2) and outputs the difference value as a comparison value (Vatc). The comparison value (Vatc) is a temperature setting value.

[0038] The current controller 11 controls a current value (Iatc) applied to the thermoelectric cooler 12 to regulate the comparison value (Vatc) to be zero.

[0039] The detailed description of the optical wavelength stability control is given by using the following equations.

[0040] The wavelength drift quantity $\Delta\lambda'$ in the wavelength stability control apparatus to which the present invention is applied is given by an equation 6 as well as an aforementioned equation 3.

$$\Delta\lambda' = \alpha \cdot \{If(tn)-If(t0)\}+(1/G) \cdot Vatc \cdot \beta \cdot \gamma \tag{6}$$

[0041] The feedback stability condition of the control system in the optical wavelength stability control apparatus to which the present invention is applied is given as equation 7.

$$Vatc = G \cdot (Vth - Vref1 + Vref2) \tag{7}$$

where Vref2 = the compensated optical wavelength drift voltage (compensated temperature)

Now, defining Vref2:

$$\begin{aligned} Vref2 &= -\alpha \cdot \Delta If /(\beta \cdot \gamma) \\ &= -\alpha \cdot \{If(tn) - If(t0)\}/(\beta \cdot \gamma) \end{aligned} \tag{8}$$

[0042] The compensated reference voltage generator 3a, shown in FIG. 1, calculates Vref2 according to equation 8.

[0043] If equations 7 and 8 are substituted into equation 6, equation 6 can be represented as equation 9.

$$\Delta\lambda' = (Vth -Vref1) \cdot \beta \cdot \gamma \tag{9}$$

[0044] If equation 9 is compared with the aforementioned equation 5 that is the wavelength drift share in the conventional method, the wavelength drift share causing the LD drive current increase/decrease of $\alpha \cdot \{If(tn) - If(t0)\}$ can be removed and it is possible to precisely stabilize the optical wavelength.

[0045] α, β are specific values of the LD determined for the respective controlled LD. γ is a value determined for the control system and has a different value depending on the control system.

[0046] For instance, considering that a Distributed Feedback (DFB) type LD is used where α=0.008(nm/mA) and β=0.095 nm/°C and the LD is controlled in a-control system where γ=10°C/V. When the LD of initial set drive current If(t0) = 60 mA deteriorates and becomes If(tn)=80 mA, Vref 2= -0.168(V) is obtained from equation 8. Therefore, a correction of an optical wavelength drift can be done by lowering the LD temperature about 1.68 °C down from the initially set temperature. If control is done hourly, the wavelength can be corrected, because it takes more than twenty hours for If(tn)-IF(to) to reach 10mA.

[0047] The detection of the LD drive current value in the LD drive current detector 1 can be made discretely. By discretely detecting, a control instability factor that two loops exist in the control system can be eliminated.

[0048] If the waiting time Ty is long enough, then the stability of a control system can be increased. However, if the time Ty is made long, the maximum drift error of the optical wavelength value $\Delta\lambda max$ becomes large.

[0049] Thus, as the discrete detection, for instance, a periodical detection can be done by setting a predicted period during which the variation of the drive current requiring a change of setting temperature will occur due to aging of the LD. Alternatively, a dynamic period can be prescribed such that the detection interval is made short in accordance with an increase of the previously detected change in drive current and long in accordance with a decrease of the previously detected change in the drive current.

[0050] The discrete sampling of the LD drive current is achieved by synchronizing the compensated reference voltage generator 3a as shown in FIG. 1 with a microcomputer using a clock frequency. By employing this sampling method, the compensated reference voltage generator 3a capable of discretely sampling the LD drive current can be simply configured.

[0051] When the LD drive current detector 1 shown in FIG. 1 detects the LD drive current value, a mean value detection can be done at a sampling time Tx. By performing the mean value detection, a deterioration of the precision control caused by sudden noises such as a power surge onto the LD drive current value can be prevented.

[0052] Moreover, it is possible to apply the combination of the discrete sampling and the above mean value detection to the present invention. In other words, the LD drive current detector 1 shown in FIG. 1 can detect the LD drive current value discretely and perform the mean value detection at the sampling time Tx. As a result, it is possible to delete two loops causing the control instability factor in the control system and to reduce an influence of the moment noise to the detected LD drive current value. Accordingly, the stability of the control system can be improved.

[0053] Based upon the present invention, the LD drive current value driving the LD is detected and the setting temperature can be set in accordance with the fluctuation of the LD drive current value. In other words, it is possible to determine a setting temperature correcting the wavelength drift share due to deterioration caused by aging and maintain the wavelength stability for a long period of time.

[0054] Further, the control instability factor caused by two loops existing in the control system can be eliminated by detecting the LD drive current value discretely.

[0055] In addition, it is possible to prevent the deterioration of the precision control from affecting the influence of sudden noises, such as a power surge, onto the LD drive current value by performing the mean value detection at the sampling time Tx to detect the LD drive current value.

[0056] While the present invention has been described above in conjunction with the preferred embodiments, one of ordinary skill in the art would be enabled by this disclosure to make various modifications to these embodiments and still be within the scope and spirit of the present invention as defined in the appended claims.

Claims

1. An optical wavelength stability control apparatus for stabilising an optical wavelength output from a laser diode (5) comprising:

   a current detector (1) which detects a laser diode drive current; and
   a thermal controller which controls the temperature of said laser diode (5) to a control target value, said thermal controller setting said control target value according to the laser diode drive current detected by said current detector (1).

2. The apparatus of claim 1, wherein said thermal controller includes a normalisation unit (2) which normalises said laser diode drive current detected by said current detector (1) as a deviation from a predetermined initial value for said laser diode drive current and sets said control target value corresponding to such normalisation.

3. The apparatus of claim 2, wherein said thermal controller includes a compensated reference voltage generator (3a, 3b) which receives a normalised value from said normalisation unit (2) and outputs a temperature setting value.

4. The apparatus of claim 3, wherein said compensated reference voltage generator (3a, 3b) also receives a current-wavelength conversion coefficient from a current-wavelength conversion coefficient decider (4) and uses said coefficient in determining said temperature setting value.

5. The apparatus of claim 1 or 2, wherein said current detector (1) detects the laser diode drive current value hourly or at a discrete time, and/or detects the mean value of said laser diode drive current value within a predetermined time.

6. The apparatus of claim 1 or 2, wherein

   said current detector (1) has period setting means for setting the time period for detecting said laser diode drive current value, and
   said period setting means sets a shorter time period if a detected increase of said laser diode drive current is large, and sets a longer period if a detected increase of said laser diode drive current is small.

7. The apparatus of any one of claims 1 to 3, further including means for monitoring the optical power output by receiving a part of said optical power output from said laser diode (5) and regulating said laser diode drive current so that the monitored optical power output is approximately equal to a predetermined control target value.

8. An optical transmitter including a plurality of laser diode modules, each having a laser diode (5), a photo diode (6), and a thermoelectric cooler (12), the optical transmitter comprising:

   a laser diode drive current detector (1) for detecting the laser diode drive current value;
   an auto power control circuit for controlling the stability of an optical power output by varying the laser diode drive current driving said laser diode (5);
   a laser diode drive current increase/decrease normalisation unit (2) for outputting the variation of said laser diode drive current value through normalisation based upon the detected laser diode drive current value;
   a compensated reference voltage generator (3a, 3b) for generating a laser diode temperature control target

value in response to the normalised variation of the laser diode drive current value;
a temperature monitor circuit (10) for detecting the laser diode temperature;
a comparator (8) for detecting the difference between said laser diode temperature and said laser diode temperature control target value; and
a current controller (11) for determining a current value to be applied to said thermoelectric cooler (12) to reduce the temperature difference detected by said comparator (8).

9. An optical multiple wavelength transmitter for transmitting light having a plurality of different wavelengths, said optical multiple wavelength transmitter comprising:

a plurality of laser diodes (5);
means for detecting respective drive current driving said plurality of laser diodes (5); and
means for controlling the respective temperatures of said plurality of laser diodes (5), wherein said controlling means includes temperature detection means for detecting the respective temperatures of said plurality of laser diodes (5), cooling means (12) for cooling the respective laser diode (5) and control means for setting a control target temperature for the respective laser diode (5) using a conversion coefficient predetermined for the respective laser diode (5) in response to the variation of the detected drive current, and controlling said cooling means (12) to regulate the respective detected temperatures of said laser diodes (5) to the set control target value.

10. The transmitter of claim 8 or 9, wherein at least two of said plurality of laser diode modules output light at different wavelengths.

11. A method for stabilising the optical wavelength output of a laser diode (5), comprising the steps of:

detecting the fluctuation of the drive current driving said laser diode (5); and
regulating the temperature of said laser diode (5) to compensate the fluctuation of said optical wavelength in accordance with the variation of the laser diode drive current.

12. The method of claim 11, wherein the temperature regulating step includes a step of normalising the detected laser diode drive current with respect to an initial laser diode drive current and outputting the result of such normalising to a compensated reference voltage generator (3a, 3b).

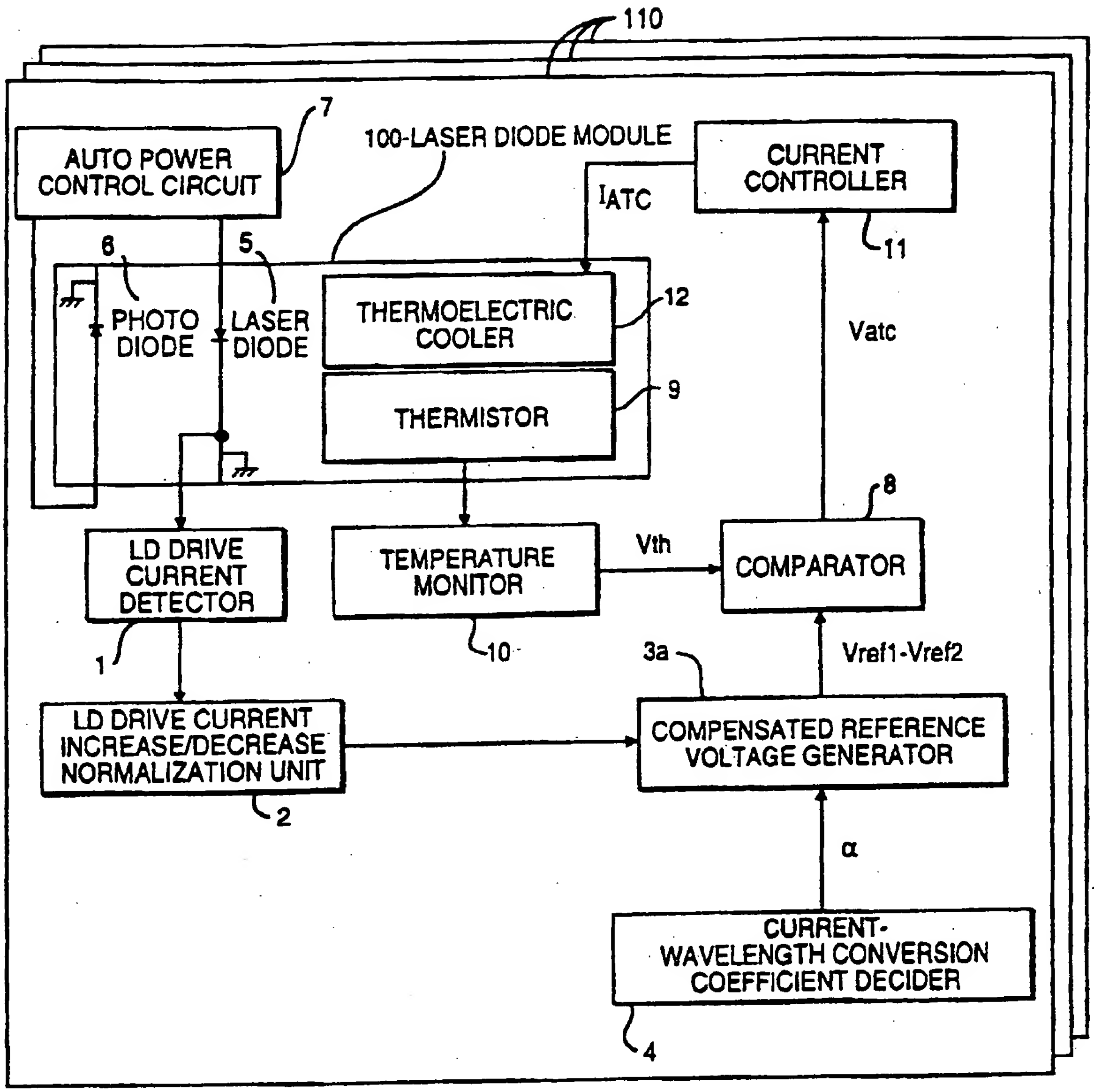
110
7
AUTO POWER CONTROL CIRCUIT
100-LASER DIODE MODULE
CURRENT CONTROLLER
IATC
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PHOTO DIODE
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THERMOELECTRIC COOLER
12
Vatc
THERMISTOR
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8
LD DRIVE CURRENT DETECTOR
TEMPERATURE MONITOR
Vth
COMPARATOR
1
10
3a
Vref1-Vref2
LD DRIVE CURRENT INCREASE/DECREASE NORMALIZATION UNIT
COMPENSATED REFERENCE VOLTAGE GENERATOR
2
α
CURRENT-WAVELENGTH CONVERSION COEFFICIENT DECIDER
4

FIG. 1

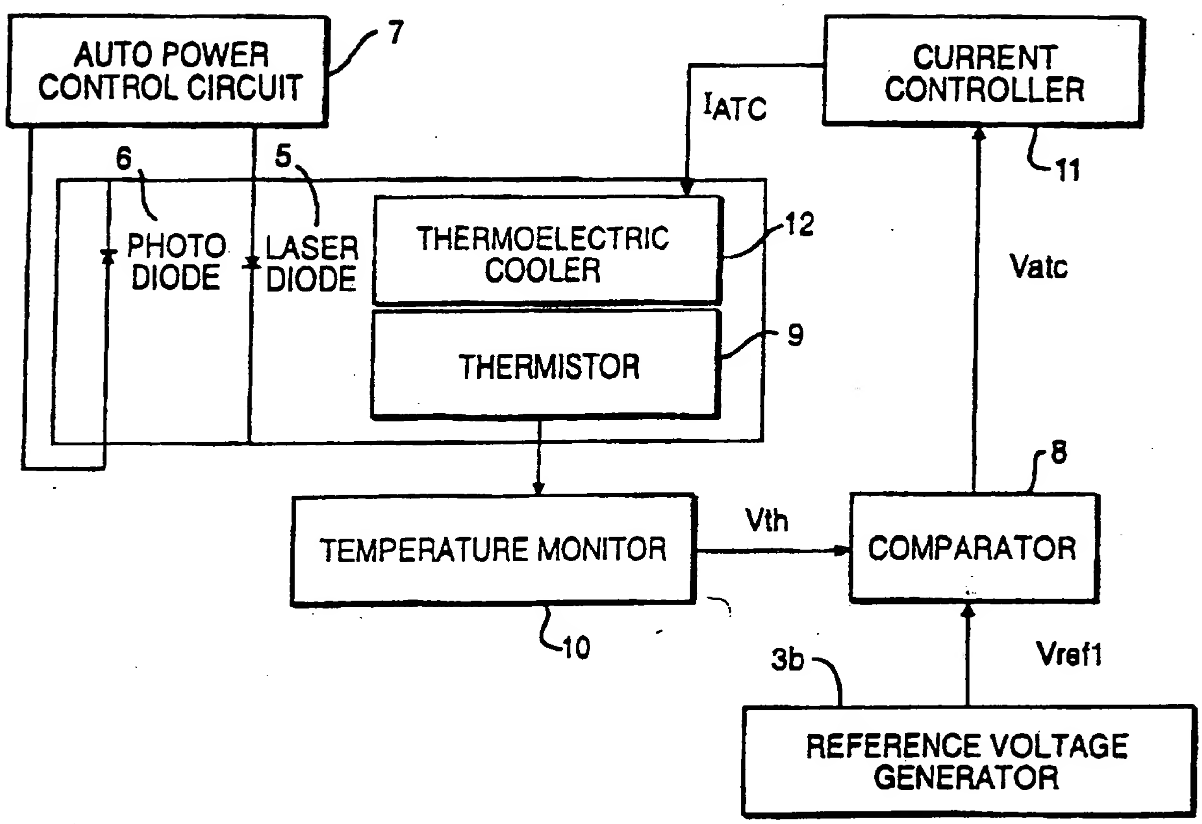
AUTO POWER CONTROL CIRCUIT
7
CURRENT CONTROLLER
IATC
11
6
5
PHOTO DIODE
LASER DIODE
THERMOELECTRIC COOLER
12
Vatc
THERMISTOR
9
8
TEMPERATURE MONITOR
Vth
COMPARATOR
10
3b
Vref1
REFERENCE VOLTAGE GENERATOR

FIG. 2

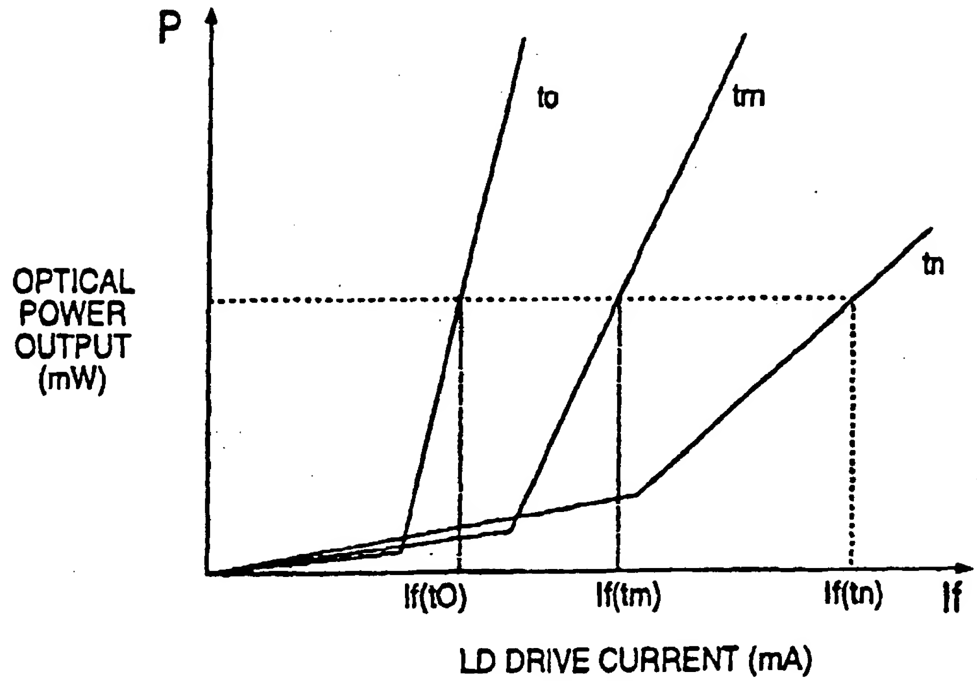
P
to
tm
tn
OPTICAL
POWER
OUTPUT
(mW)
If(tO)
If(tm)
If(tn)
If
LD DRIVE CURRENT (mA)

FIG. 3

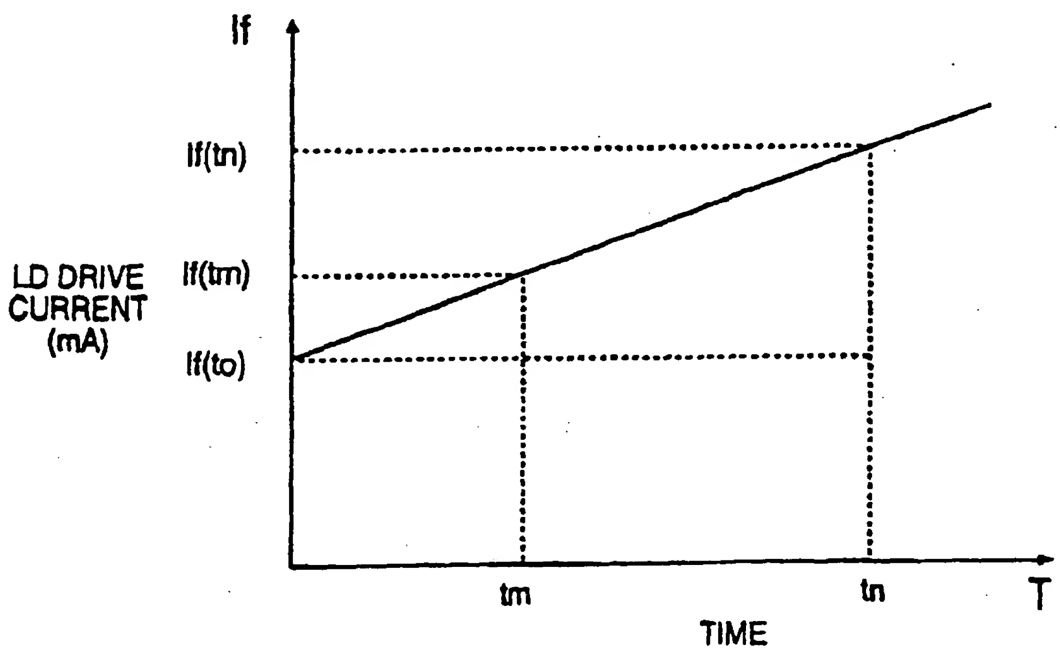
If
If(tn)
LD DRIVE
CURRENT
(mA)
If(tm)
If(to)
tm
tn
T
TIME

FIG. 4

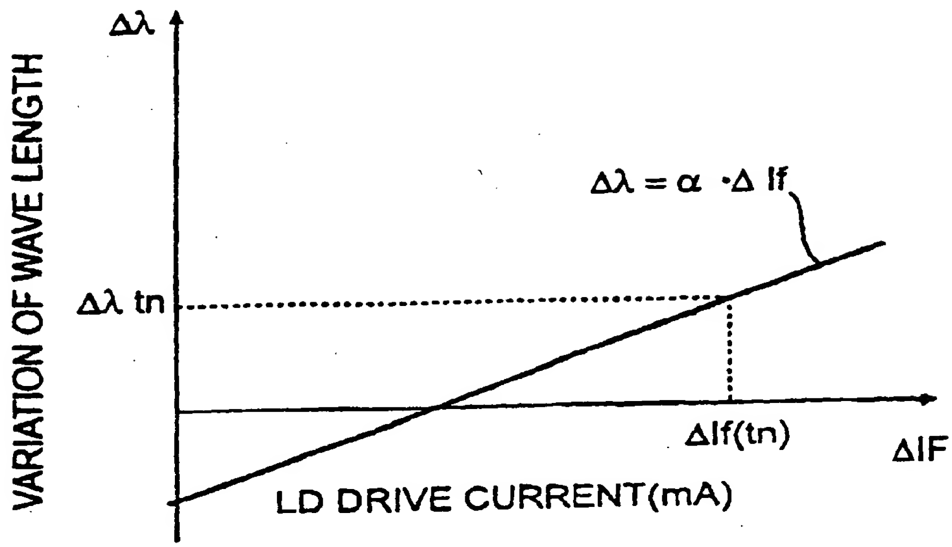
Δλ
VARIATION OF WAVE LENGTH
Δλ = α ·Δ If
Δλ tn
ΔIf(tn)
ΔIF
LD DRIVE CURRENT(mA)

FIG. 5

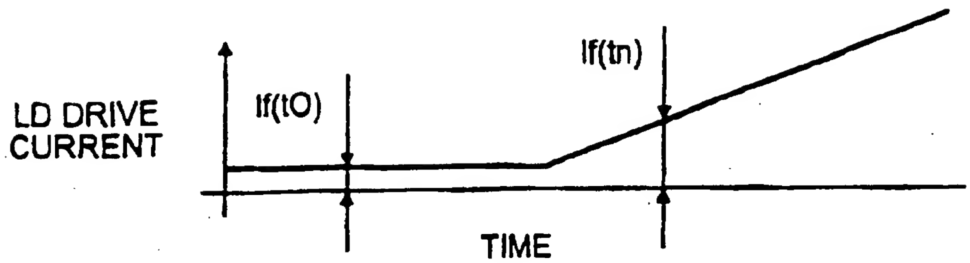

FIG. 6(A)

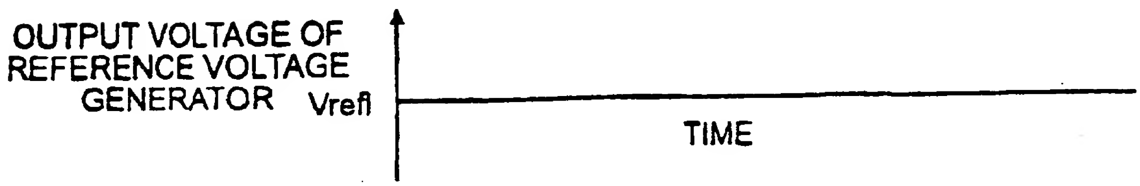

FIG. 6(B)

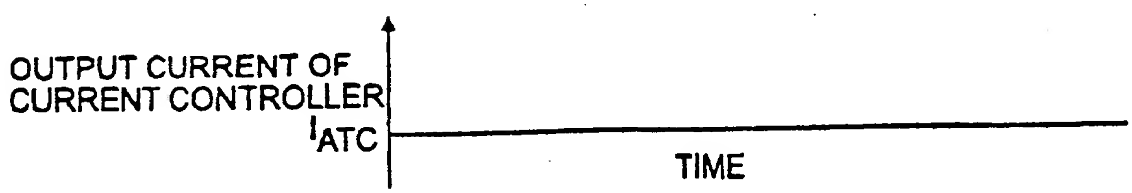

FIG. 6(C)

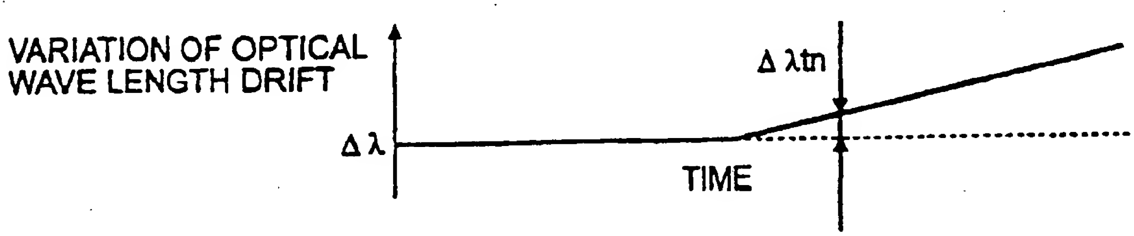

FIG. 6(D)

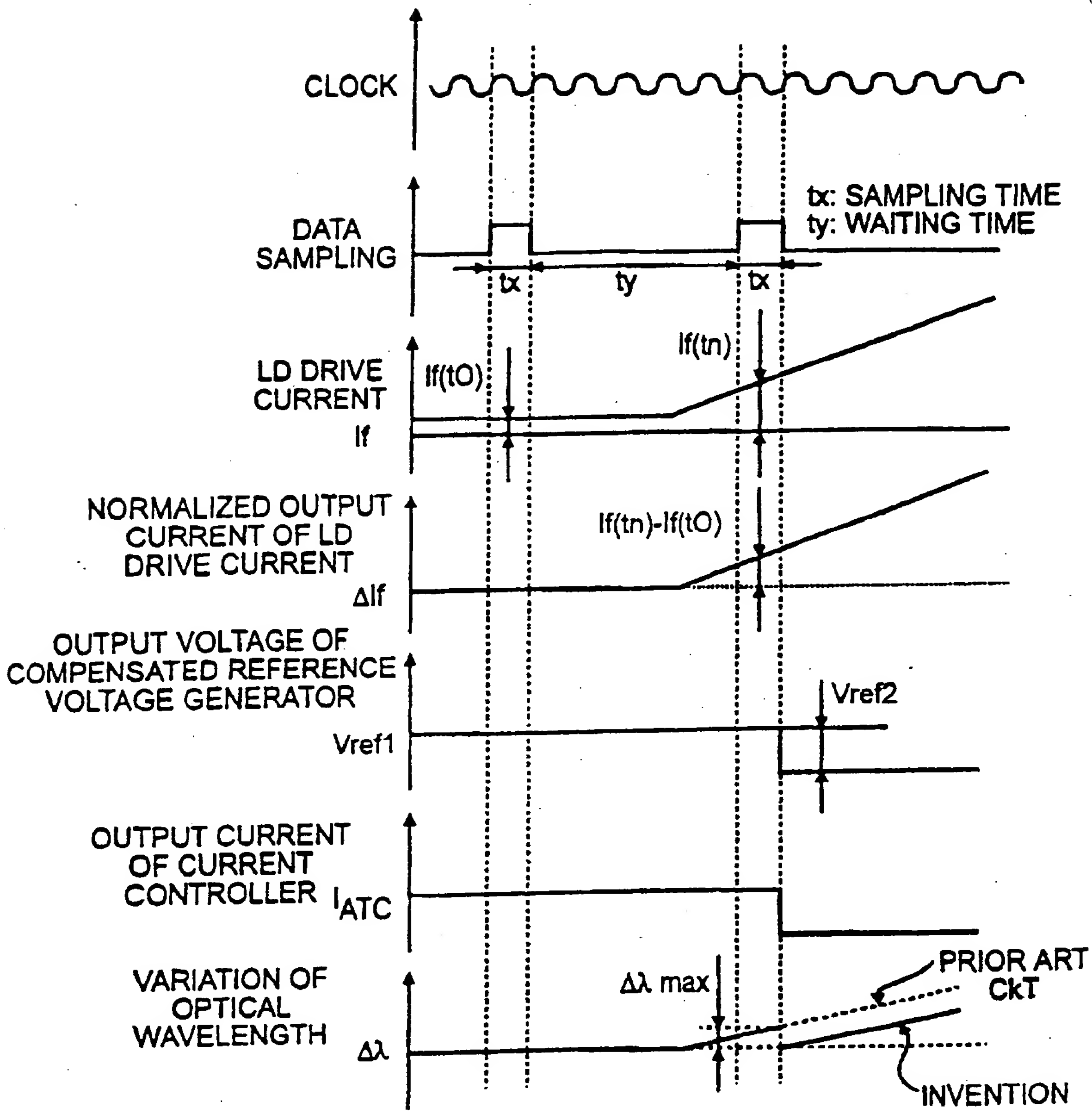
CLOCK
tx: SAMPLING TIME
ty: WAITING TIME
DATA SAMPLING
tx
ty
tx
LD DRIVE CURRENT
If
If(tO)
If(tn)
NORMALIZED OUTPUT CURRENT OF LD DRIVE CURRENT
ΔIf
If(tn)-If(tO)
OUTPUT VOLTAGE OF COMPENSATED REFERENCE VOLTAGE GENERATOR
Vref1
Vref2
OUTPUT CURRENT OF CURRENT CONTROLLER
IATC
VARIATION OF OPTICAL WAVELENGTH
Δλ
Δλ max
PRIOR ART CkT
INVENTION

FIG. 7

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European Patent Office
Office européen des brevets

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(54) Optical wavelength stability control apparatus and optical transmitter

(57) An optical transmitter includes a plurality of optical wavelength stability control apparatus, each of which is capable of compensating a wavelength drift by varying the laser diode drive current. Each of the optical wavelength stability control apparatus detects the laser diode drive current, which is controlled by an auto power control circuit, by using a laser diode drive current detector (1). The laser diode drive current is normalised by a laser diode drive current increase/decrease normalisation unit (2). A laser diode temperature control target value is generated at a compensated reference voltage generator (3a, 3b), in response to the normalised laser diode drive current, to control the current value applied to a thermoelectric cooler (12) so that the output value of a temperature monitor circuit (10) approaches a predetermined laser diode temperature control target value.

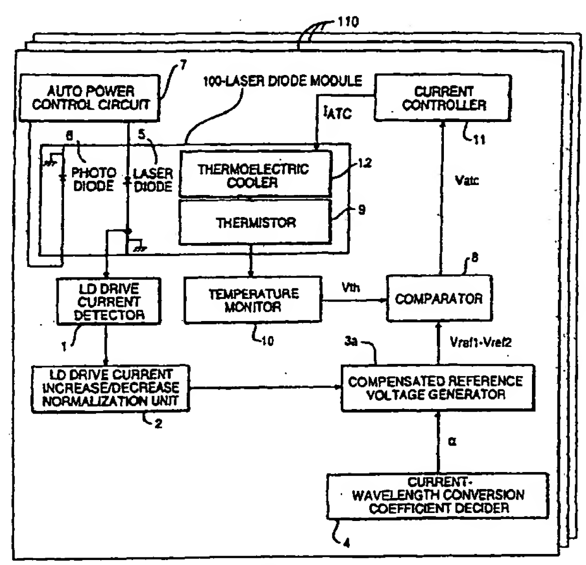

FIG. 1

EP 0 920 095 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 12 1983

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	WO 97 01203 A (COHERENT INC ;JOHNSON JOHN K (US); LOFTHOUSE ZEIS JAY T (US)) 9 January 1997 (1997-01-09) * page 7, line 14-32 * * page 8, line 15-31 * ---	1-3,5, 7-12	H01S5/068 H01S5/0687
X	DE 37 06 635 A (SPINDLER & HOYER KG) 15 September 1988 (1988-09-15) * column 4, line 31-48 * ---	1,11	
X	DE 42 12 777 A (ROHDE & SCHWARZ) 28 October 1993 (1993-10-28) * column 4, line 18-39 * -----	1,11	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
H01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	25 March 2002	Jobst, B

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 98 12 1983

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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25-03-2002

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			JP	11508408 T	21-07-1999
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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

(19) BUNDESREPUBLIK DEUTSCHLAND

DEUTSCHES PATENT- UND MARKENAMT

(12) **Offenlegungsschrift**

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(51) Int. Cl.[7]:
H 01 S 5/068
H 01 S 5/062
H 01 L 33/00

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(72) Erfinder:
Rau, Ernst, Dipl.-Ing., 79189 Bad Krozingen, DE

(56) Entgegenhaltungen:

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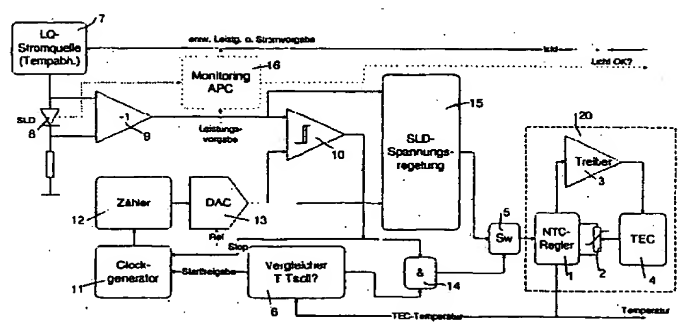
US	46 83 573
WO	97 01 203

Die folgenden Angaben sind den vom Anmelder eingereichten Unterlagen entnommen

Prüfungsantrag gem. § 44 PatG ist gestellt

(54) Verfahren und Schaltungsanordnung zur Regelung der Wellenlänge eines Strahlung emittierenden Halbleiterbauelements

(57) Das Verfahren und die erfindungsgemäße Schaltungsanordnung zur Regelung der Wellenlänge eines Strahlung emittierenden Halbleiterbauelements (8), insbesondere einer Superlumineszenz- oder Laserdiode, dessen (deren) Emissionswellenlänge sowohl von der Temperatur des Bauelements (8) als auch vom Strom abhängig ist und das mittels eines ersten (inneren) Regelkreises (1 bis 4) in einer auf eine bestimmte Temperatur geregelten Umgebung mit einem von einem jeweils gesetzten Temperaturwert (T_{soll}) abhängig vorgegebenen Strom betrieben wird, sieht erfindungsgemäß die Anwendung eines in Kaskade zum ersten Regelkreis geschalteten zweiten (äußeren) Regelkreises (9 bis 15) vor, mittels dessen nach dem Erreichen des Temperaturwerts (T_{soll}) die Durchlaßspannung am Halbleiterbauelement (8) überwacht und bei Abweichung von einem Spannungssollwert ein Nachführsignal für den ersten (inneren) Regelkreis zur Temperaturnachführung erzeugt wird.
Mit der Erfindung wird eine wesentlich genauere Überwachung der tatsächlichen Betriebstemperatur des Halbleiterbauelements (8) erreicht und damit eine stabilere Wellenlänge garantiert, was beispielsweise bei der Anwendung in faseroptischen Kreiseln zu einer deutlichen Erhöhung der Skalenfaktorgenauigkeit beiträgt.



DE 198 28 427 A 1

Beschreibung

Die Erfindung betrifft ein Verfahren sowie eine Schaltungsanordnung zur Regelung der Wellenlänge eines Strahlung emittierenden Halbleiterbauelements, dessen Emissionswellenlänge sowohl von der Temperatur des Bauelements als auch vom Strom abhängig ist, und das in einer temperaturgeregelten Umgebung mit einem von dem jeweils gesetzten Temperaturwert abhängig vorgegebenen Strom betrieben wird.

Für hochgenaue lichtoptische Meßeinrichtungen, wofür faseroptische Kreisel oder allgemeiner bestimmte optische interferometrische Meßeinrichtungen Beispiele sind, wird eine Lichtquelle mit einer bestimmten, möglichst konstanten Wellenlänge benötigt, um beispielsweise aus der Phasenverschiebung des Lichts in der Interferometeranordnung eine Drehrate bestimmen zu können. Die Wellenlänge von Strahlung emittierenden Halbleiterbauelementen, insbesondere von Superlumineszenzdioden (SLDs) oder Laserdioden, ist sowohl von der Temperatur als auch vom Strom durch dieses Halbleiterbauelement abhängig. Im Falle von Faserkreiseln werden für weniger genaue Anwendungen SLDs ohne Kühlung bzw. Temperaturüberwachung eingesetzt. Für genauere Anforderungen jedoch werden diese Halbleiterbauelemente in einer temperaturgeregelten Umgebung, beispielsweise eingebaut in einen thermoelektrischen Kühler (TEC), betrieben, der in der Regel mit Peltier-Elementen bestückt ist, so daß sowohl Kühlung als auch Heizung möglich ist mit dem Vorteil einer hochgenauen Temperatureinstell- bzw. -regelmöglichkeit. Die Temperatur im Gehäuse der Kühl/Heizeinrichtung wird durch einen Temperaturfühler, insbesondere einen Thermistor oder NTC überwacht.

Bekannt ist es also mittels eines Regelkreises, der nachfolgend als erster Regelkreis bezeichnet wird, aus der vom Temperaturfühler gemessenen Temperatur einen vorzeichenrichtigen Strom für den thermoelektrischen Kühler zu ermitteln, so daß ein vorgegebener Temperatur-Sollwert genau eingehalten wird. Diese bekannte und bisher eingesetzte Regelung hat allerdings einen Nachteil:
Trotz geringer räumlicher Abstände in dem gemeinsamen Gehäuse entspricht die jeweils vom Temperaturfühler angezeigte Temperatur in der Regel nicht der wahren Chiptemperatur des Halbleiterbauelements, beispielsweise der SLD. Dadurch entsteht trotz sehr genauer Einhaltung der Temperaturvorgabewerte eine mehr oder weniger geringe Abweichung der von der Lichtquelle emittierten Lichtwellenlänge.

Der Erfindung liegt damit die Aufgabe zugrunde, die festgestellten Einflüsse auf die Wellenlänge zu beseitigen, die sich daraus ergeben, daß die tatsächliche Betriebstemperatur des in temperaturgeregelter Umgebung betriebenen Lichtquellen-Bauelements nicht genau der von einem Temperaturfühler angezeigten Temperatur entspricht.

Die Erfindung basiert zunächst auf dem Gedanken, daß eine andere Stellgröße als die Temperatur in der Umgebung der Lichtquelle gefunden werden muß, auf die geregelt werden kann. Hierzu macht sich die Erfindung die physikalische Erkenntnis zunutze, daß die Spannung bei bestimmten Licht emittierenden Halbleiterbauelementen, insbesondere bei SLDs über einen weiten Bereich direkt proportional ist zur Temperatur. Geht man also von einem konstant gehaltenen Strom durch das SLD-Bauelement aus, so kann von der Durchlaßspannung direkt auf die Temperatur geschlossen werden.

Hinsichtlich des Verfahrens zur Regelung der Wellenlänge eines Strahlung emittierenden Halbleiterbauelements, dessen Emissionswellenlänge sowohl von der Temperatur des Bauelements als auch vom Strom abhängig ist, und das in einer temperaturgeregelten Umgebung mit einem von dem jeweils gesetzten Temperaturwert T_{soll} abhängig vorgegebenen Strom I_{SLD} betrieben wird, ist die Erfindung dadurch gekennzeichnet, daß die Betriebsspannung des Halbleiterbauelements erfaßt und gegen einen durch den gesetzten Temperaturwert T_{soll} festgelegten Spannungswert verglichen wird, und daß bei einer Abweichung der beiden Spannungswerte die Umgebungstemperatur des Bauelements nachgeregelt wird.

Gemäß der Erfindung wird also die Durchlaßspannung des Licht emittierenden Halbleiterbauelements, beispielsweise an der SLD als Regelgröße eines äußeren (zweiten) Regelkreises in einem kaskadierten Regelsystem eingesetzt.

Eine Regelungsanordnung oder Regelschaltung für die Wellenlänge eines Strahlung emittierenden Halbleiterbauelements, insbesondere einer SLD, deren Emissionswellenlänge sowohl von der Temperatur des Bauelements als auch vom Strom abhängig ist und das in einer mittels eines ersten Regelkreises auf eine bestimmte Temperatur geregelte Umgebung mit einem von dem jeweils gesetzten Temperaturwert abhängig vorgegebenen Strom betrieben wird, ist erfindungsgemäß gekennzeichnet durch einen äußeren, in Kaskade zum ersten Regelkreis geschalteten zweiten Regelkreis, der nach dem Erreichen des Temperaturwerts T_{soll} für die Umgebungstemperatur die Durchlaßspannung am Halbleiterbauelement überwacht und bei Abweichung von einem Spannungssollwert ein Nachführsignal für den ersten Regelkreis zur Temperaturnachführung abgibt.

Bedingt durch Schwankungen bei der Herstellung können geringfügige Verschiebungen des Absolutwerts der optimierten Durchlaßspannung auftreten, die jedoch im vorliegenden Fall unerheblich sind, da nur die Temperaturabweichung als solche ausgewertet wird. Dazu wird zu einem bestimmten Zeitpunkt, der entweder vom Temperaturfühler, also vom Thermistor oder NTC gesteuert wird, oder der durch eine Mindestwartezeit, in der das System garantiert eingeschwungen ist, erreicht wird, die momentane Spannung über dem Halbleiterbauelement, insbesondere die Diodenspannung festgehalten. Dies kann auf verschiedene Weise geschehen, z. B. durch Verwendung eines Analogspeichers, oder, wie nachfolgend in einem Ausführungsbeispiel beschrieben, mittels eines digitalen Potentiometers. Die "absolute Temperatur" wird hier durch den inneren (ersten) Regelkreis gewährleistet.

Mit Bezug auf die einzige Figur der beigefügten Zeichnung wird nachfolgend ein bevorzugtes und erprobtes Ausführungsbeispiel der Erfindung beschrieben.

Ein Licht emittierendes Halbleiterbauelement, insbesondere eine SLD **8** wird von einer temperaturabhängig steuerbaren Stromquelle **7** gespeist, deren Stellgröße I_{SLD} entsprechend dem Temperaturwert T_{soll} von einer externen Quelle, z. B. dem Prozessor der Regelschaltung eines faseroptischen Kreisels, vorgegeben wird. Die SLD **8** ist in einen thermoelektrischen Kühler **20** eingebaut und wird mittels eines ersten, inneren Regelkreises auf der optimierten gesetzten (Betriebs-) Temperatur T_{soll} gehalten. Der erste Regelkreis des thermoelektrischen Kühlers **20** umfaßt in bekannter Weise einen durch einen Temperaturfühler **2** (Thermistor oder NTC) gesteuerten Regler **1** (NTC-Regler), der über einen Leistungsvertärker **3** (Treiber) ein thermoelektrisches Kühlaggregat **4** (Peltier-Elemente) mit dem notwendigen Betriebsstrom versorgt. Die jeweilige Betriebstemperatur des Kühlaggregats **4** wird durch den Temperaturfühler **2** erfaßt. Ist ein bestimmter Temperaturwert erreicht, so wird über eine hier nicht dargestellte Prozessoreinheit der Steuerstromwert I_{SLD} eingestellt, durch den bezogen auf den gesetzten Temperaturwert T_{soll} über eine steuerbare Licht-Stromquelle **7** eine gewünschte optische Ausgangsleistung

bei einer bestimmten Wellenlänge für die SLD **8** gewährleistet ist.

Wie bereits erwähnt, wurde jedoch festgestellt, daß die vom Temperaturfühler **2** angezeigte Temperatur nicht genau der wahren Temperatur des Chips der SLD **8** entspricht. Basierend auf der Erkenntnis, daß die Spannung der SLD **8** über einen weiten Bereich direkt proportional zur Betriebstemperatur ist, wird mit der Erfindung ein zweiter äußerer Regelkreis vorgeschlagen, mit dem zunächst die Spannung an der SLD **8** über einen Differenzverstärker **9** den einen Eingang eines Komparators **10** beaufschlagt, dessen zweiter Eingang im dargestellten Ausführungsbeispiel mit dem Analogausgang eines digitalen Potentiometers verbunden ist, bestehend aus einem Taktgenerator **11**, einem Zähler **12** und einem D/A-Wandler (DAC) **13**. Der Ausgang des Komparators **10** liefert einerseits ein Stop-Signal für den Taktgenerator (Clockgenerator) **11** und beaufschlagt andererseits den einen Eingang eines UND-Glieds **14**. Der andere Eingang des UND-Glieds **14** liegt an einem Ausgang eines Vergleichers **6**, der feststellt, ob die vom Temperaturfühler **2** gemessene Temperatur innerhalb eines vorgegebenen Temperaturfensters, also insbesondere in einem engen Bereich um den gesetzten Temperaturwert T_{soll} liegt. Der Vergleicher **6** liefert außerdem ein Startfreigabesignal für den Taktgenerator **11**. Das UND-Glied **14** steuert einen Schalter **5** (Torschaltung), über den dem Regler **1** eine zusätzliche Stellgröße von einem Spannungsregler **15** zuführbar ist, der eingangsseitig durch den Ausgang des D/A-Wandlers **13** als Sollgröße beaufschlagt ist. Aus der Sollgröße, die aus dem D/A-Wandler **13** bereitgestellt wird, und aus der Istgröße, die der Differenzverstärker **9** bildet und die sich nicht mehr ändert, wird eine Regelabweichung ermittelt, die wiederum als Führungsgröße an den Regler **1** weitergegeben wird, wenn der Schalter **5** geschlossen ist. Ein einmal eingestellter Strom für die Lichtquelle **7** wird nicht mehr variiert, d. h. es wird von der oben erwähnten physikalischen Beobachtung ausgegangen, daß eine Spannungsänderung an der SLD **8** ihren Ursprung in einer Temperaturänderung hat.

Die soweit beschriebene Regelungsschaltung arbeitet wie folgt:
Nach dem Einschalten der Stromversorgung ist der Schalter **5** zunächst offen. Der Regler **1** des ersten Regelkreises für den thermoelektrischen Kühler **20** mit Temperaturfühler **2**, Treiber **3** und thermoelektrischen Kühlelementen **4** stellt eine gesetzte Temperatur T_{soll} intern ein. Als zweite Größe neben dem Betriebsstrom für die Kühlelemente **4** gibt der Regler **1** noch die Temperatur aus, und zwar einerseits an den (nicht dargestellten) Prozessor zur Vorgabe der Steuergröße I_{SLD} sowie an den Vergleicher **6**. Ist der Temperaturwert T_{soll} erreicht, so wird die Stromquelle **7** über den Steuerstromwert I_{SLD} auf einen konstanten Strom eingestellt. Die Spannung an der SLD **8** wird über den Differenzverstärker **9** zum Komparator **10** geführt. Sobald die Temperatur im Bereich von T_{soll} liegt, gibt der Vergleicher **6** den Taktgenerator **11** frei, der über den Zähler **12** und den D/A-Wandler **13** eine Spannung an den zweiten Eingang des Komparators **10** legt. Sobald der Komparator **10** Spannungsgleichheit mit der Spannung über der SLD **8** erkennt, schaltet sein Ausgangswert um, sperrt damit den Taktgenerator 1 1 und schaltet über das UND-Glied **14** den Schalter **5** frei, wobei die zweite Bedingung für die UND-Verknüpfung das in der Schaltung des Vergleichers **6** festgestellte Erreichen des Temperaturfensters ist. Für den Vergleicher **6** lassen sich gut sogenannte Fensterdiskriminatoren einsetzen. Für den gleichen Zweck eignen sich jedoch auch einfache Zeitverzögerungsschaltungen. Nach dem Schließen des Schalters **5** übernimmt die SLD-Spannungsregelung **15** als übergeordneter (zweiter) Regelkreis die Temperaturregelung für den thermoelektrischen Kühler **20** und damit auch für die SLD **8**. Ersichtlicherweise ist dabei die vom D/A-Wandler **13** gelieferte Spannung die Sollgröße, während die Spannung über der SLD **8** die Istgröße wiedergibt.

Eine vorteilhafte Abwandlung bzw. Ergänzung der Schaltungsanordnung besteht darin, anstelle bzw. ergänzend zur Steuergröße I_{SLD} eine automatische Regelung der optischen Leistung der SLD **8** vorzusehen. Dazu wird ein Teil des von der SLD **8** emittierten Lichts durch einen Strahlteiler (nicht dargestellt) auf eine Monitor-Diode gegeben und damit wird über einen weiteren Regelkreis **16**, allgemein gebräuchlich unter der Bezeichnung "Automatic Power Control" (APC), der Strom der SLD **8** bestimmt. Ist ein bestimmter Sollwert der optischen Leistung erreicht, so wird der Betriebsstrom der SLD **8** bzw. die Steuergröße I_{SLD} ebenfalls "eingefroren".

Ein Vorteil dieser – in der Zeichnung gestrichelt wiedergegebenen – Schaltungsvariante oder Schaltungsergänzung besteht darin, daß bei jedem Einschalten der SLD **8** die gleiche optische Leistung geliefert wird. Aus den dabei festgestellten Unterschieden im Betriebsstrom und aus der Betriebszeit, die in einer übergeordneten Elektronik ausgewertet werden können, lassen sich Informationen über die Alterung der SLD **8** bzw. der Laserdiode gewinnen, woraus eine Warnmeldung über einen eventuellen Ausfall ableitbar ist.

Mit der Erfindung wird eine deutlich bessere Stabilität der Wellenlänge des Licht emittierenden Halbleiterbauelements, also insbesondere der SLD **8** erreicht.

Patentansprüche

1. Verfahren zur Regelung der Wellenlänge eines Strahlung emittierenden Halbleiterbauelements, dessen Emissionswellenlänge sowohl von der Temperatur des Bauelements als auch vom Strom abhängig ist, und das in einer temperaturgeregelten Umgebung mit einem von dem jeweils gesetzten Temperaturwert (T_{soll} abhängig vorgegebenen Strom betrieben wird, **dadurch gekennzeichnet**, daß
   – die Betriebsspannung des Halbleiterbauelements (**8**) erfaßt und gegen einen durch den gesetzten Temperaturwert (T_{soll}) festgelegten Spannungswert verglichen wird und daß
   – bei einer Abweichung der beiden Spannungswerte die Umgebungstemperatur des Bauelements (**8**) nachgeregelt wird.
2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß als Strahlung emittierendes Halbleiterbauelement eine Superlumineszenzdiode verwendet wird.
3. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß als Strahlung emittierendes Halbleiterbauelement eine Laserdiode verwendet wird.
4. Regelungsanordnung für die Wellenlänge eines Strahlung emittierenden Halbleiterbauelements (**8**), dessen Emissionswellenlänge sowohl von der Temperatur des Bauelements als auch vom Strom abhängig ist und das in einer mittels eines ersten Regelkreises (**1, 2, 3, 4**) auf eine bestimmte Temperatur geregelten Umgebung mit einem von dem jeweils gesetzten Temperaturwert (T_{soll}) abhängig vorgegebenen Strom (I_{SLD}) betrieben wird, gekennzeichnet durch einen äußeren in Kaskade zum ersten Regelkreis geschalteten zweiten Regelkreis (**9** bis **15**), der nach dem Erreichen des gesetzten Temperaturwerts (T_{soll}) die Durchlaßspannung am Halbleiterbauelement (**8**) überwacht und bei Abweichung von einem Spannungssollwert ein Nachführsignal für den ersten Regelkreis zur Temperaturnachführung abgibt.

5. Regelungsanordnung nach Anspruch 4, dadurch gekennzeichnet, daß das Halbleiterbauelement (8) eine Superlumineszenzdiode (SLD) oder eine Laserdiode ist.

6. Regelungsanordnung nach Anspruch 4 oder 5, gekennzeichnet durch einen Komparator (10), der die Durchlaßspannung am Halbleiterbauelement (8) gegen eine durch den gesetzten Temperaturwert (T_{soll}) bei dem vorgegebenen konstanten Strom (I_{SLD}) bestimmte Spannung vergleicht und bei Abweichung eine Torschaltung (14, 5) aktiviert, über welche das von einem Spannungsregler (15) des zweiten Regelkreises gelieferte Nachführsignal den ersten Regelkreis beaufschlagt.

7. Regelungsanordnung nach Anspruch 6, dadurch gekennzeichnet, daß der Spannungsregler (15) durch eine in Abhängigkeit von einem Vergleich zwischen dem gesetzten Temperaturwert (T_{soll}) und der tatsächlichen Umgebungstemperatur (T) des Bauelements (8) generierte Spannung als Sollgröße beaufschlagt ist.

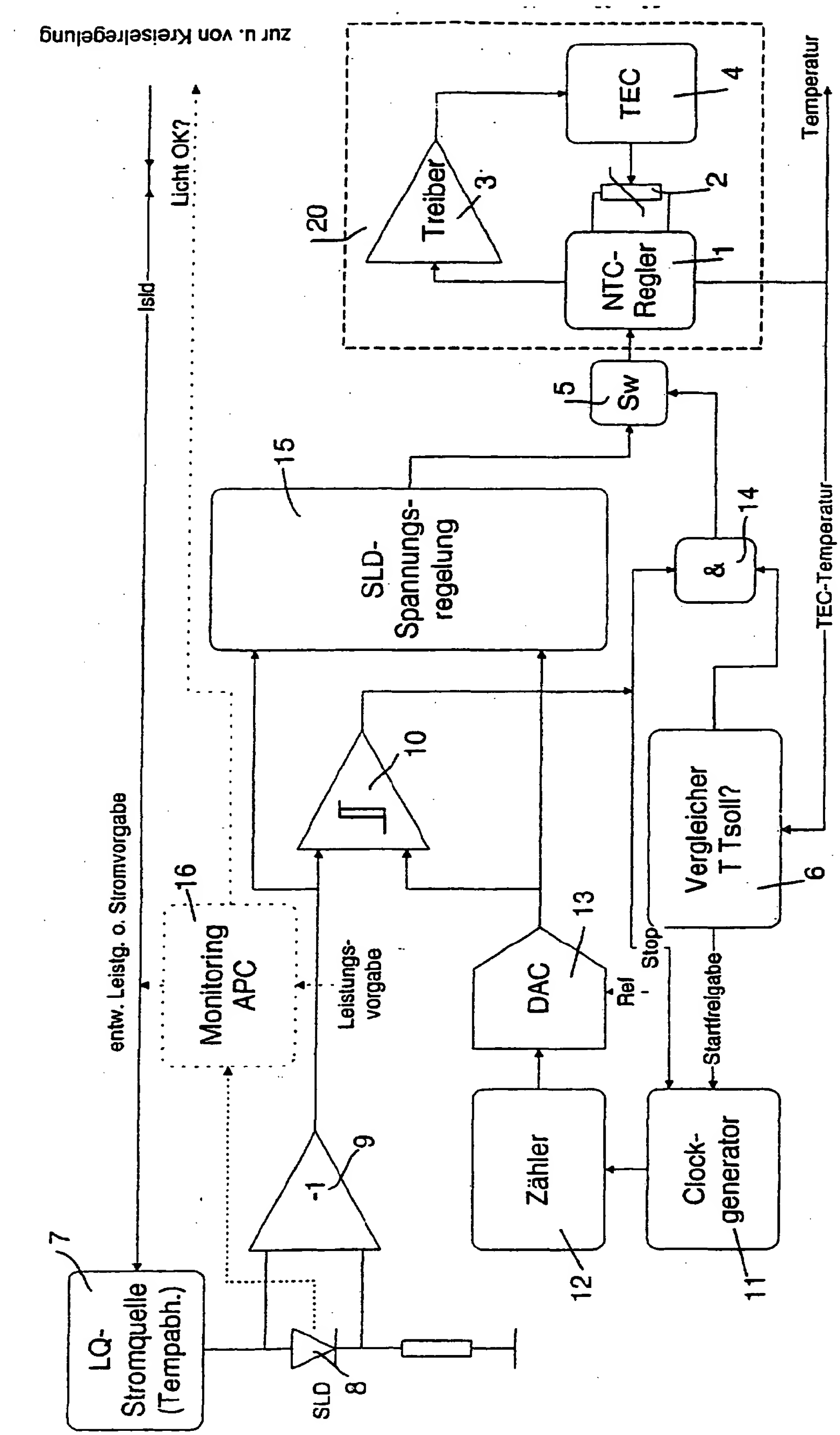
8. Regelungsanordnung nach Anspruch 7, dadurch gekennzeichnet, daß die Sollgröße für den Spannungsregler (15) über ein digitales Potentiometer (11, 12, 13) generiert wird, das in Abhängigkeit von dem Temperaturvergleich ($T = T_{soll}$?) gestartet und in Abhängigkeit vom Spannungsvergleich am Komparator (10) deaktiviert wird.

9. Regelungsanordnung nach Anspruch 8, dadurch gekennzeichnet, daß das digitale Potentiometer durch einen aufgrund des Temperaturvergleichs zu startenden und in Abhängigkeit vom genannten Spannungsvergleich stillsetzbaren Taktgenerator (11), einen durch diesen gesteuerten Zähler (12) und einen diesem nachgeschalteten Digital/Analog-Wandler (13) gebildet ist.

10. Regelungsanordnung nach einem der vorstehenden Ansprüche 4 bis 9, dadurch gekennzeichnet, daß die Vorgabe des Betriebsstrom für das Halbleiterbauelement (8) über eine automatische Regelung der optischen Leistung des Halbleiterbauelements bestimmt ist.

Hierzu 1 Seite(n) Zeichnungen

- Leerseite -


zur u. von Kreiselregelung
Licht OK?
Isld
entw. Leistg. o. Stromvorgabe
LQ-Stromquelle (Tempabh.)
7
SLD
8
-1
9
Monitoring APC
16
Leistungs-vorgabe
10
SLD-Spannungs-regelung
15
DAC
13
Ref
Zähler
12
Clock-generator
11
Stop
Startfreigabe
Vergleicher T Tsoll?
6
&
14
Sw
5
NTC-Regler
1
2
Treiber
3
TEC
4
20
TEC-Temperatur
Temperatur